Analysing Air Pollution Exposure in London

Report to Greater London Authority

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Executive Summary

Air quality in London has improved in recent years as a result of policies to reduce emissions, primarily from road transport. However, recently updated maps of pollution concentrations for 2010 show exceedences of the annual mean NO_2 and the daily PM_{10} EU Limit Values. Improvements are planned to address these, as recently announced in the Mayor's package of air quality measures. The research described in this report considers changes in pollution exposure in London in recent years, predictions for future years and considers how exposure varies across the social gradient in London.

The Mayor of London has recently announced a package of air quality measures to be delivered across the next several years. This includes a new Ultra Low Emission Zone for central London, further improvements to the bus fleet, reduced emissions at construction sites and improvements to the energy efficiency of buildings. A new £20m Air Quality Fund will support the Boroughs in tackling local air quality hotspots and a Cycling Vision which includes nearly £1 billion of investment in cycling.

Through the research described in this report, the GLA is seeking to understand inequalities in access to clean air in London and to consider how this will be improved by planned air pollution controls. Previous work for Defra and the Environment Agency found that exposure to air quality is unequal across the social spectrum, with the most deprived communities disproportionately exposed to the highest air pollution levels. The aim of the work described in this report was to build on these previous research findings and to provide current analysis, specifically for London, using recently updated air quality concentration data based on the latest version of the London Atmospheric Emissions Inventory.

Annual average air quality concentrations of NO_2, PM_{10} and $PM_{2.5}$ across London in 2010 at a 20m resolution were obtained from the Environment Research Group (ERG) at Kings College London. Average air pollution concentrations within small geographical areas (LSOAs) were calculated and then combined with Census data on resident population (totals and by age group), Index of Multiple Deprivation scores for each LSOA and the locations and attributes of primary schools.

This study has found that there is currently significant exposure of the London population to levels of NO_2 above the EU limit value and that this exposure is predicted to decline significantly (86%) by 2020. However, current modelling results show that in 2020 there will still be more than 300,000 people living in locations with average NO_2 above the EU limit value (**Figure E1**). In contrast, average concentrations of particles (PM_{10} and $PM_{2.5}$) were, by 2010, already within EU Limit Values for the annual average concentrations (**Figure E2**).

Figure E1 Estimate of population exposed to NO_2 concentrations in exceedence of the EU Air Quality Objective (40 µg/m3) for 2008 to 2020

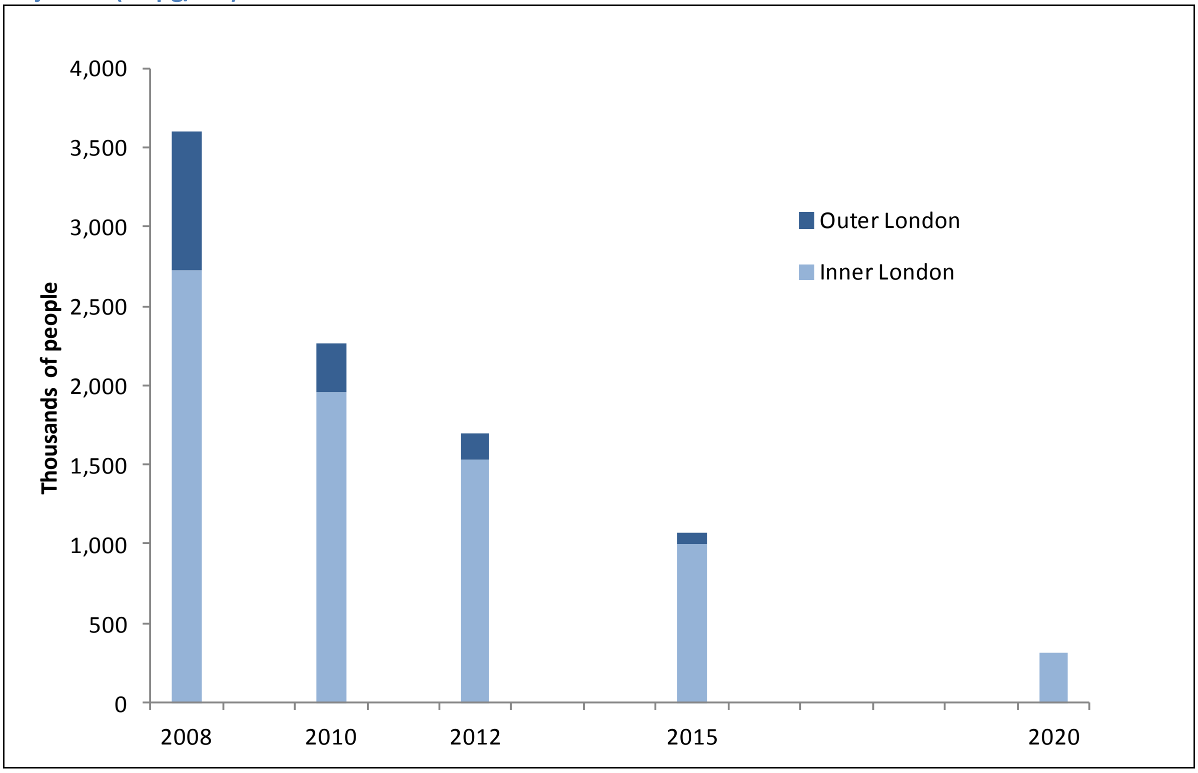
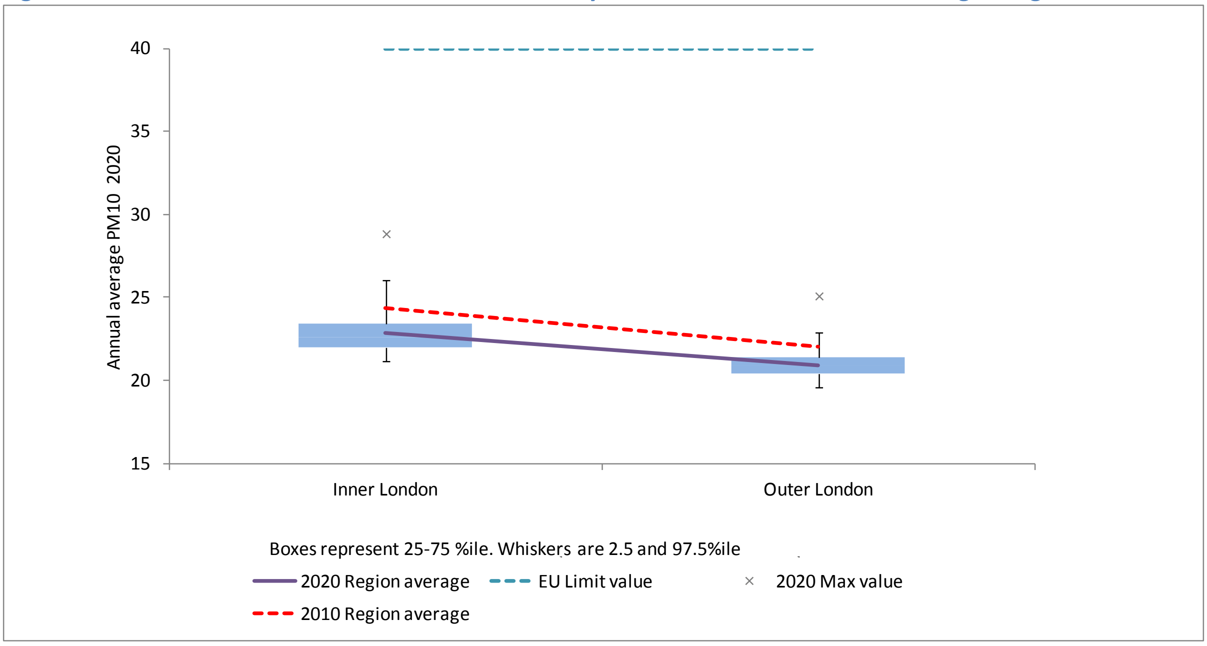
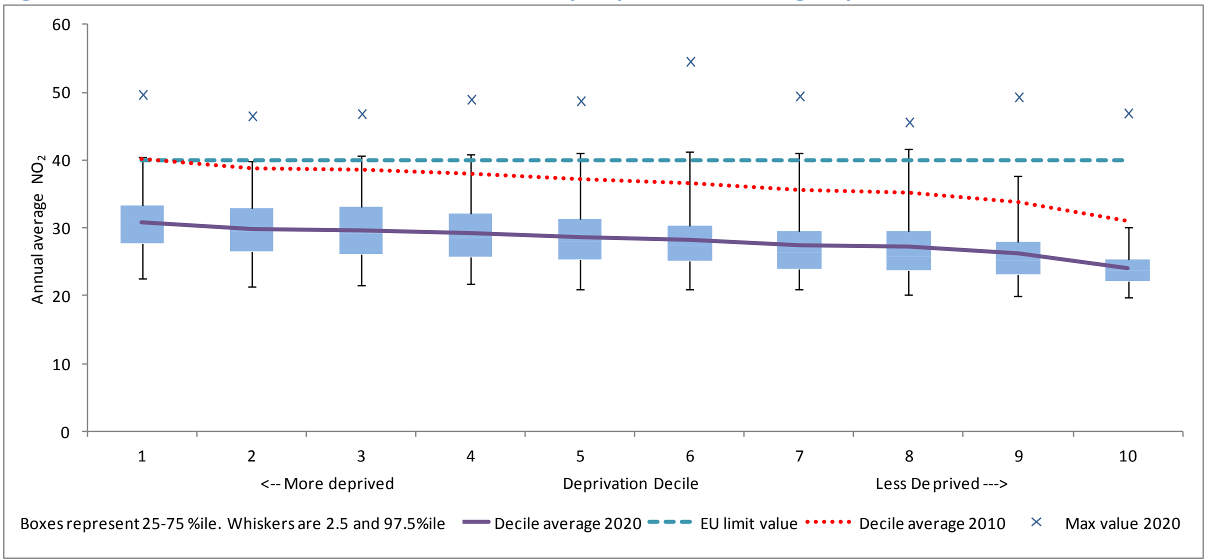


Figure E2 Pollution concentrations of PM10 in 2020 by Inner and Outer London showing change since 2010



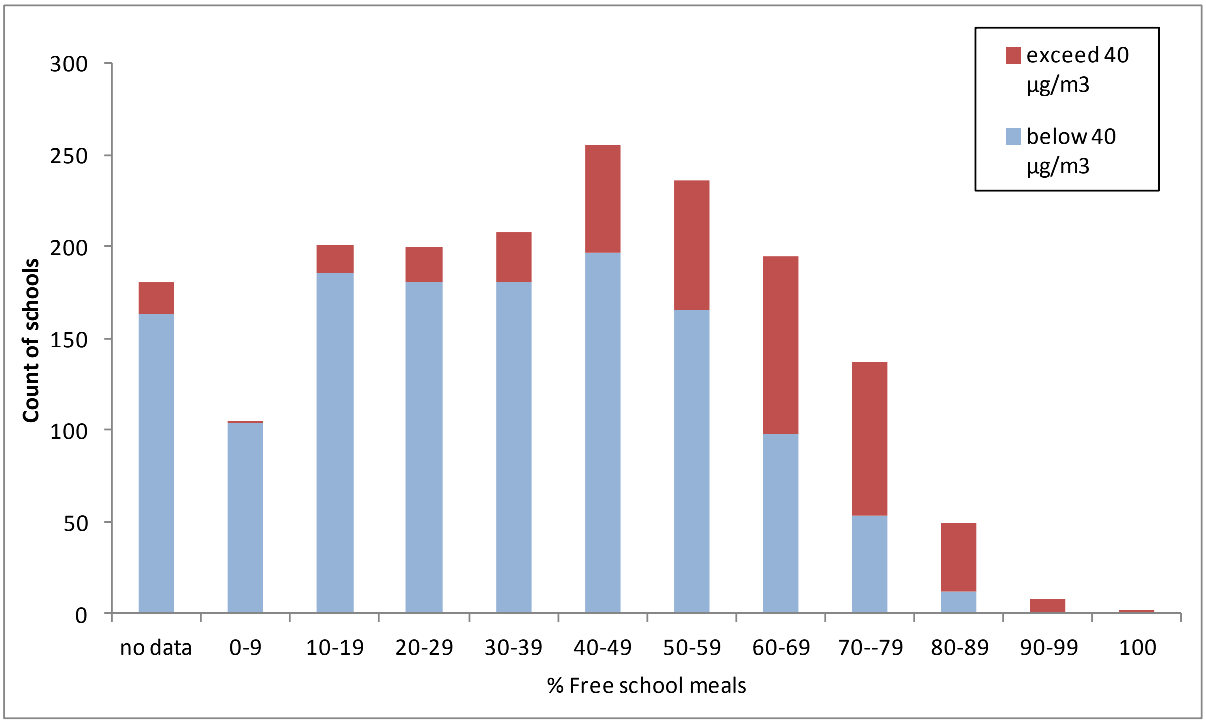
Populations living in the most deprived areas are on average currently more exposed to poor air quality than those in less deprived areas. 51% of the LSOAs within the most deprived 10% of London have concentrations above the NO_2 EU limit value. This is in contrast to 1% above the NO_2 EU limit value in the 10% least deprived areas. However there is a wide variation in pollution concentration values across the social gradient, with all deciles showing a large range between minimum and maximum values (**Figure E3**). Inequalities are predicted to reduce by 2020 as a result of new policies predominantly resulting from reductions in road transport emissions. Further measures and plans announced recently (and not included in the modelling) are expected to improve this picture.

Figure E3 Pollution concentrations of NO_2 in 2020 by Deprivation decile groups of LSOAs in London 2020



Newham, Brent, Redbridge, Hackney and Tower Hamlets are the Boroughs that have the highest proportion of most deprived populations (top 30% deprived) in London's areas of worst air quality. Tower Hamlets, Camden, Southwark, Islington and City of Westminster are the Boroughs that have the highest numbers of people living in London's worst air quality areas. These Boroughs in particular need targeted action to reduce inequalities in access to clean air.

Figure E4 Count of schools grouped by the proportion of pupils eligible for Free School Meals and an NO_2 exceedence



In 2010, there were 1777 primary schools in London of which 433 were in locations where average concentrations exceed the NO_2 EU limit value. Of these 433 primary schools, 82% were deprived schools. By contrast, of the 1344 primary schools that were not exposed to above EU limit values of NO_2, 39% were deprived. (**Figure E4**). In combination with other measures to reduce pollution, we recommend that consideration should be given as to what further action can be taken at schools particularly those in deprived areas. The numbers of schools exposed to levels above the EU limit value is predicted to significantly reduce by 2020 but there is still a clear disparity between deprived and non-deprived schools.

The predicted air quality maps used in this analysis included planned measures to reduce air pollution emissions but did not include the impacts of further additional measures and plans recently announced by the Mayor of London. These are expected to further improve the air quality by 2020 beyond that quantified here. The Ultra Low Emission Zone is planned to focus specific reductions in the central London area and will help to reduce exposure to the highest levels predicted for 2020. It is also important that these further measures target improvements in deprived communities in an effort to reduce inequalities in access to clean air and therefore to help reduce health inequalities particularly among children..

Contents

1 Introduction

Air quality in London has improved in recent years as a result of policies to reduce emissions, primarily from road transport. However, recently updated maps of pollution concentrations for 2010 show exceedences of the annual mean NO_2 and the daily PM_{10} EU Limit Values. Improvements are planned to address these, as recently announced in the Mayor's package of air quality measures. The research described in this report considers changes in pollution exposure in London in recent years, predictions for future years and considers how exposure varies across the social gradient in London.

Air pollution above EU limit values poses a risk to health (see **Table 1**), and this is particularly significant for susceptible groups such as those who are already experiencing health problems which can be exacerbated by poor air quality. Age is an important factor in susceptibility to health effects of air pollution, key impacts being asthma in children and chronic obstructive pulmonary disease and coronary heart disease in older adults.

Table 1 Air pollution EU Air Quality Directive Limit Values and health impacts of NO_2, PM_{10} and $PM_{2.5}$

Pollutant	Concentration measured as	EU Limit Value	Health Impacts
Nitrogen Dioxide (NO_2)	Annual mean 24 hour mean	40 µg/m^3 200 µg/m^3 not to be exceeded more than 18 times a year	NO_2 irritates the airways of the lungs, increasing the symptoms of those suffering from lung diseases
PM_{10}	Annual mean 24 hour mean	40 µg/m^3 50 µg/m^3 not to be exceeded more than 35 times a year	Fine particles can be carried deep into the lungs where they can cause inflammation and a worsening of heart and lung diseases
$PM_{2.5}$	Annual mean	25 µg/m^3	

The Equalities Act 2010 clarified the GLA's responsibilities in terms of equalities and established a new Equality Duty. The Equality Duty applies across Great Britain to public bodies and to other organisations when they are carrying out public functions. It requires public bodies to have due regard to the need to:

- eliminate unlawful discrimination, harassment, victimisation and any other conduct prohibited by the Act;
- advance equality of opportunity between people who share a protected characteristic and people who do not share it; and
- foster good relations between people who share a protected characteristic and people who do not share it.

Through the research described in this report, the GLA is seeking to understand inequalities in access to clean air in London and to consider how this will be improved by planned air pollution controls. The recent availability of detailed census data for 2011 and the updated pollution concentration maps based on the 2010 LAEI data has meant that it is now timely to make this assessment.

The impacts of the following committed measures are included in the new predicted air quality maps for 2015 and 2020:

- Retrofit of 900 Euro III buses with Selective Catalyst Reduction (SCR) to reduce NO_x and NO_2 emissions;
- 1,150 Hybrid buses by 2016;
- An age limit for Taxis; and
- Further phases of the Low Emission Zone introduced in 2012 to cover larger vans and tighten standards for heavy vehicles.

The Mayor of London has also recently announced a further package of air quality measures and plans to be delivered in over the next few years (not yet quantified in the air quality maps). This included:

- A new Ultra Low Emission Zone for central London, subject to a feasibility study.
- Retiring the remaining 900 oldest Euro III buses in TfL's fleet and replacing them with super-clean Euro VI buses.
- Accelerating the roll out of hybrid buses, with 1,600 to be on the road by 2016, including 600 New Buses for London which are the cleanest and greenest bus of their type. This will be equivalent to around 20% of TfL's bus fleet.
- New measures to reduce emissions and clean up construction sites.
- Retrofitting a further 24,000 homes, public buildings and schools with energy efficiency measures.
- A new £20m Air Quality Fund to support the Boroughs in tackling local air quality hotspots.
- Cycling Vision which includes nearly £1 billion of investment in cycling. This is expected to have significant health, mode shift and air quality benefits.

Air quality and access to green spaces have been identified as a one of the significant factors in health inequalities by the Marmot review[1] alongside other factors in addition to deprivation such as housing, fuel poverty, transport and diet. Deprivation and health inequalities are closely linked but this current study seeks to consider if exposure to poor air quality also varies across the social gradient within London, and therefore whether there is likely to be a compound effect on the health of these groups. The relationship between exposure and social gradient has been investigated before, but this study provides a more up-to-date evidence base for London.

The analysis described in this report follows similar work undertaken at the national scale in 2006, funded by Defra[2]. That project found that the most deprived communities are disproportionately exposed to the highest air pollution levels. Inequalities in the distribution of pollutant concentrations were observed for England, Scotland and Northern Ireland for nitrogen dioxide (NO_2) and particulate matter (PM_{10}), and for sulphur dioxide (SO_2) in England and Northern Ireland. For NO_2 and PM_{10}, this distribution was largely explained by the high urban concentrations (primarily caused by road transport emission sources), and the higher proportion of deprived communities in urban areas.

The Environment Agency has also undertaken work that investigated the correlation between health, deprivation and environmental quality in Greater London[3]. Correlations were found between air quality and deprivation. These findings supported earlier work. However due to the complex nature of the deprivation and environmental quality datasets, and the lack of causality, the correlations with health impacts were not strong.

The aim of the work described in this report was to build on these previous research findings and to provide current analysis, specifically for London, using recently updated air quality concentration data based on the latest version of the London Atmospheric Emissions Inventory[4]. This provides the GLA with an evidence base of quantified exposure to air pollution across the whole population and the level of inequalities that exist within this pattern of exposure. Understanding in detail the spatial

[1] http://www.instituteofhealthequity.org/projects/fair-society-healthy-lives-the-marmot-review

[2] Air Quality and Social Deprivation in the UK: an environmental inequalities analysis. Report to Defra, June 2006. http://uk-air.defra.gov.uk/reports/cat09/0701110944_AQinequalitiesFNL_AEAT_0506.pdf

[3] A scoping report: Understanding the relationship between health, deprivation and environmental quality in Greater London. Environment Agency. http://cdn.environment-agency.gov.uk/geth0308bnsv-e-e.pdf

[4] LAEI http://data.london.gov.uk/taxonomy/keywords/laei

nature of such inequalities is important in the development of policies to reduce inequalities and in the wider context of sustainable development. This report also presents results from the consideration of exposure in the context of age distribution to assess whether the elderly and young populations are disproportionately exposed to high levels of air pollution. The young are particularly susceptible to air pollution, and this study therefore also considers exposure at school locations.

1.1 Report outline

This report presents estimates of current and future population exposure to poor air quality and how this exposure varies across the social gradient of deprivation as well as by age. **Section 2** describes the data and methods of analysis that have been used. **Section 3** presents estimates of total population exposure. **Section 4** presents data on levels of exposure compared to levels of deprivation and how this varies across different areas of London. **Section 5** analyses exposure of young people and specifically considers exposure at deprived primary schools. **Section 6** briefly considers the levels of air pollution exposure of older people. **Section 7** analyses changes in pollution levels predicted for 2020 to consider if the inequality in exposure will change with time and what are the significant components of change causing these reductions. **Section 8** presents conclusions of this study.

2 Data and Methods

2.1 Air quality pollutant concentrations

Annual average air quality concentrations of NO_2, PM_{10} and $PM_{2.5}$ across London in 2010 at a 20m resolution were obtained from the Environment Research Group (ERG) at Kings College London[5]. These concentration data are in the form of recently updated maps based on the latest 2010 LAEI emissions estimates.

In order to combine the pollution concentration data with population statistics the pollution maps were aggregated to Lower Super Output Areas (LSOAs) by calculating an average air pollution concentration within each LSOA based on the 20m grid squares that it covers. The maximum pollutant concentration was also calculated for each LSOA to indicate the maximum potential exposure for populations living in that local area.

Maps of predicted pollution concentrations for 2015 and 2020 were also obtained from ERG. These are also based on estimated future emissions levels using data in the latest LAEI and have been used to make estimates of future exposure. Further maps estimating source specific contributions to current and future concentrations were also provided by ERG to allow the assessment of how changes in future emissions from roads and other sources impact on exposure.

The statistical analysis undertaken considered pollutant concentrations within groups of LSOAs defined as deciles i.e. a ranked list of LSOAs divided into ten groups containing an equal number of LSOAs. Average concentration data for LSOAs within deciles have been summarised as “box and whisker” plots, which are graphs that show the 2.5^{th}, 25^{th}, 75^{th} and 97.5^{th} percentiles and the maximum values within the distribution of values in each decile. This provides a very useful visual representation of the variation in pollution levels across the population variable (see **Figure 3**).

[5] ERG air pollution maps http://www.londonair.org.uk/london/asp/annualmaps.asp

2.2 Index of Multiple Deprivation

The ONS have developed an established measure of deprivation known as the Index of Multiple Deprivation (IMD). IMD data across London for 2010 were obtained, 2010 data being available at LSOA scale[6]. The IMD is made up of 7 domains of deprivation, each of which is compiled from a number of indicators. These indicators and domains are then given a weighting according to their perceived contribution to overall deprivation. These include:

- Income deprivation
- Employment deprivation
- Health deprivation
- Disability, education, skills and training deprivation
- Barriers to housing and services
- Crime and living environment deprivation.

The living environment includes air quality, houses without central heating and road traffic accidents involving pedestrians and cyclists. Air quality is included in the IMD, but it only makes up 1.5% of the total index and therefore it is not enough to bias the results. The overall scores for each domain are combined using the weightings to provide an overall IMD score.

For our analysis the LSOAs were ranked by IMD score and the rankings have been used to divide the LSOAs into decile (10%) ranges within which average and maximum pollution exposure has been considered using the air concentration maps (see below). Counts of population by IMD decile have also been used to consider the social make-up of areas of high pollution within London.

2.3 Population data

Data from the 2011 Census at LSOA[7] have be used to calculate total population and also the percentage of children and young people (under 19) and percentage of elderly people (over 65) within each LOSA. LSOAs were ranked twice and split into deciles according to the percentage of the population in these two groups. This approach provided two separate indicators of concentration of the age groups within the population of the LSOA, giving a metric similar to that available from the IMD and therefore allows the analysis techniques to be consistent.

2.4 Population projections

Ward based population projections were available from the London data store[8]. These were linked geographically to the LSOAs in order to calculate ward based age-specific growth factors for future years (2015, 2020) and hence estimate the LSOA populations for 2015 and 2020.

2.5 Schools data

Data on primary school locations were made available by the GLA, and data on percentage of pupils eligible for free school meals were obtained from published school league tables[9]. Data on Free School Meals is often used as a proxy measure of deprivation[10].

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6 http://data.london.gov.uk/datastore/package/indices-deprivation-2010

7 Table PP04 2011 Census: Usual resident population by five year age group, Middle Layer Super Output Areas (MSOAs) and Lower Layer Super Output Areas (LSOAs) in England and Wales

8 GLA Ward-Level Population Projections 2012 Round, SHLAA-Based http://data.london.gov.uk/datastore/package/gla-2012rnd-SHLAA-ward-proj

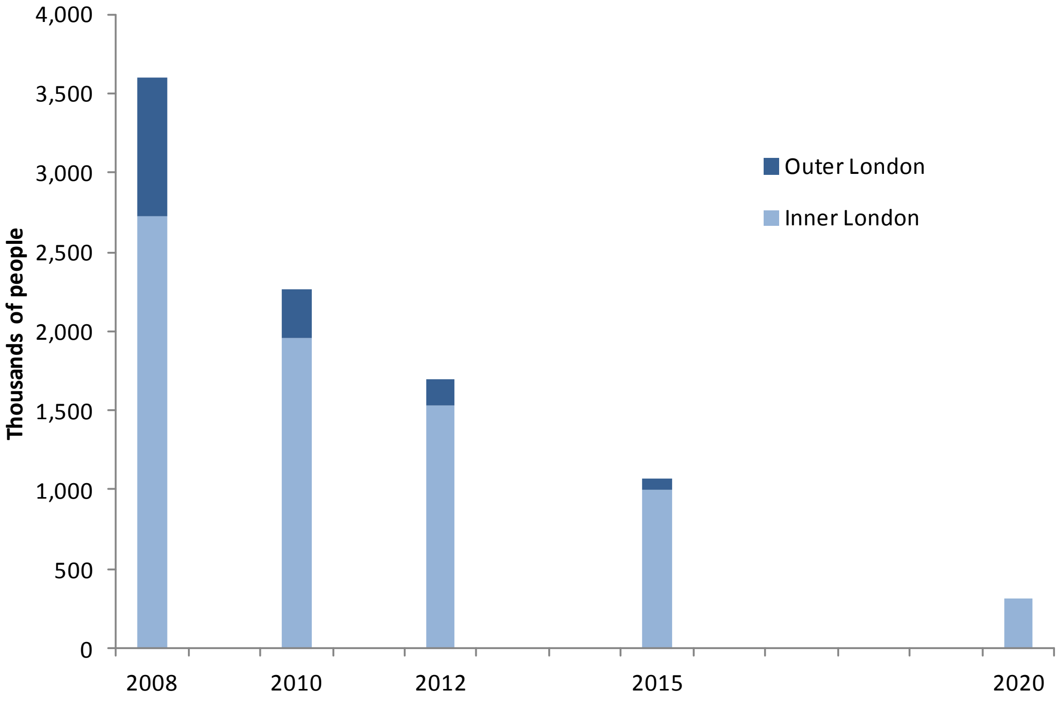
9 http://www.guardian.co.uk/news/datablog/2012/dec/13/primary-school-league-tables-2012-data#data

10 Underperforming schools and deprivation: A statistical profile of schools below the floor standards in 2010, Research Report DFE-RR141, Department for Education June 2011

3 Air Pollution Exposure of Total Population

The combination of updated pollution maps for 2010 and new census data for 2011 provides the opportunity to calculate new estimates of the population exposed to levels of pollution that exceed the EU Air Quality Directive limit value of 40 µg/m^3 for NO_2. **Figure 1** shows that in 2012 approximately 1.7 million people in London, the majority of which are located in inner London, were living in areas with average NO_2 concentrations above the EU limit value. The graph shows that exposure has significantly declined since 2008 and is predicted to continue to decline to 2020.

Figure 1 Estimate of population exposed to NO_2 concentrations in exceedence of the EU Air Quality Objective (40 µg/m3) for 2008 to 2020



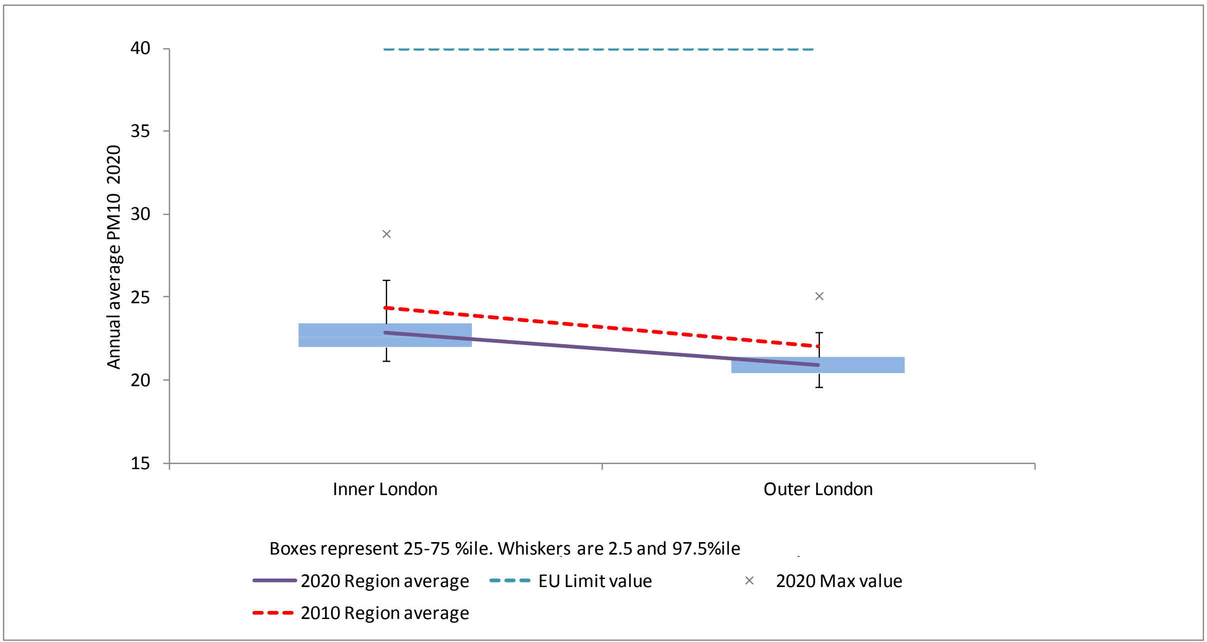
		Population	
Year	Inner London	Outer London	London Total
2008	2,731,000	870,000	3,601,000
2010	1,956,000	311,000	2,267,000
2012	1,530,000	164,000	1,694,000
2015	1,000,000	71,000	1,071,000
2020	310,000	0	310,000

The estimates presented above are calculated by summing the populations within LSOAs that have an average concentration above the EU limit value (average across the 20m resolution modelled locations within the LSOA). There is geographical variability in the pollution level within each LSOA and therefore not all dwellings will be directly exposed to concentrations above the limit value. However, these LSOAs are small areas (with a population of around 1500) and within people's daily activities it is assumed that they will be in close proximity to concentrations above the limit value if the average exceeds it.

Reductions in emissions of particles over recent years have resulted in annual average concentrations of PM_{10} and $PM_{2.5}$ in London now complying with EU limit values for these pollutants.

This is shown in **Figure 2** below. However it is important to acknowledge that exceedences of the EU limit value for daily PM_{10} concentrations are still predicted in some locations in 2020. Analysis of the pattern of these exceedences shows that their locations are very similar to those for NO_2 but in fewer locations, confined to roads.

Figure 2 Pollution concentrations of PM10 in 2020 by Inner and Outer London showing change since 2010



4 Air Pollution Exposure in Areas of Deprivation

Each LSOA in London has been allocated to a deprivation decile, defined as 10 percent groups of LSOAs ranked by their Index of Multiple Deprivation scores. Each decile contains 476 LSOAs within which the air pollution concentration has been calculated by averaging air pollution in each modelled 20m grid square. Air pollution data for each deprivation decile has been summarised to show the trend in pollution across the social gradient of deprivation. These are shown in **Figure** 3.

Figure 3 Pollution concentrations by deprivation decile groups in London 2010 (a) NO_2, (b) PM_{10}, (c) $PM_{2.5}$

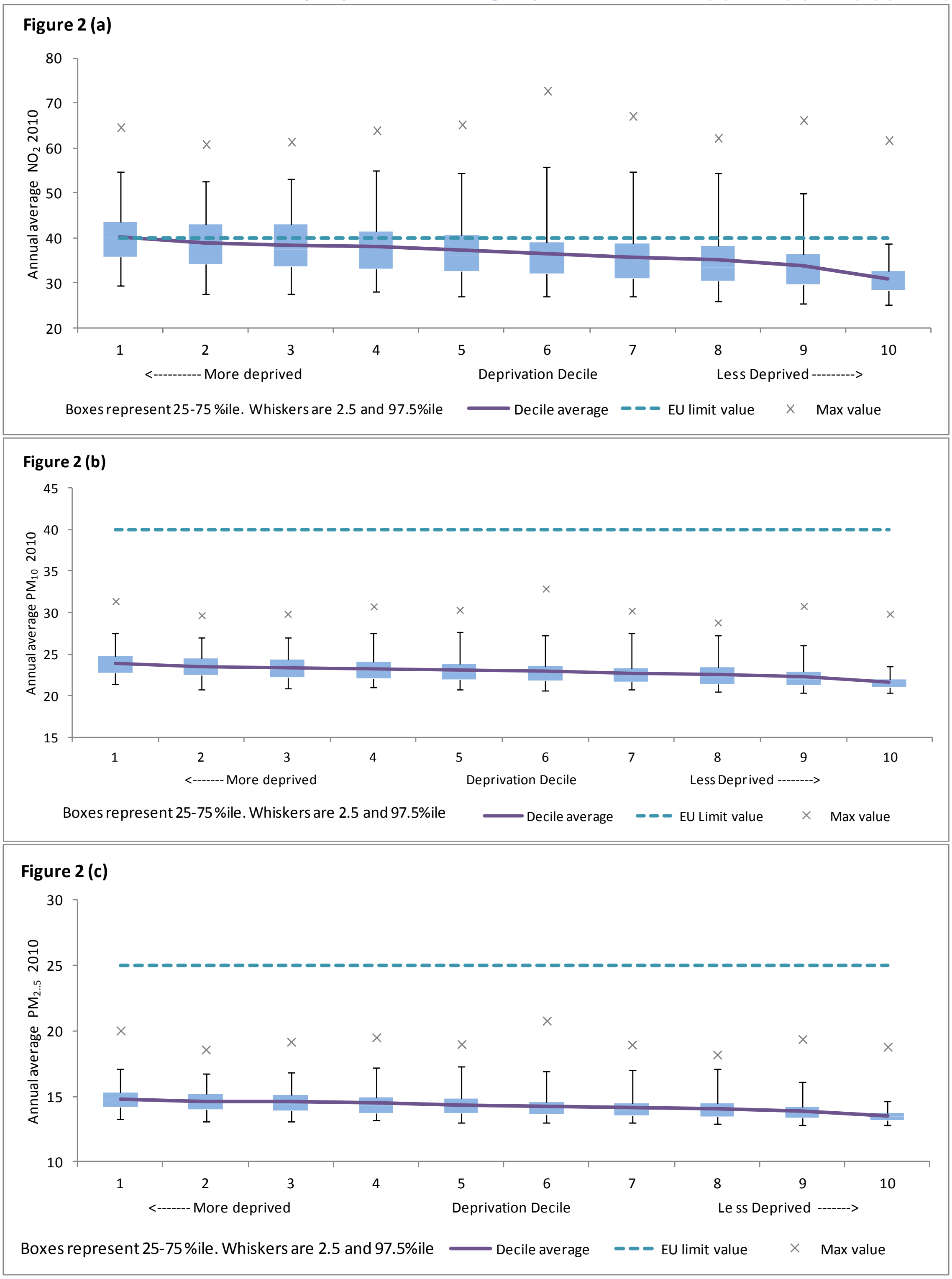


Figure 3 illustrates both the trend of average NO_2 concentration levels across the deprivation deciles whilst also showing the variability that exists within each deprivation decile. Average concentration levels of NO_2 (i.e. the decile average line) are highest in decile 1, the most deprived, with an average NO_2 concentration level of 40.2 µg/m^3, which just exceeds the EU limit value. 51% of LSOAs within decile 1 have average concentrations above the EU limit value, and the highest average concentration is 64.6 µg/m^3. As the level of deprivation declines so does the average level of NO_2 concentration and the lowest average concentration level of NO_2 (31.0 µg/m^3) occurs in decile 10, the least deprived. 1% of LSOAs in decile 10 have an average concentration above the EU limit value.

The variability in average NO_2 concentration levels in the LSOAs also reduces as the level of deprivation declines (i.e. the area of the blue box in **Figure 3**), and the whisker plots (showing the range of 2.5 to 97.5 percentiles) show that the range of pollution that 95% of the population in the least deprived areas is generally lower than that of the more deprived areas and for NO_2 95% of the population is exposed to average concentrations below the EU limit value. There is no trend in the maximum values with deprivation levels because there are peak concentrations occurring in locations across the social gradient

A possible explanation for the general trend may be the link between lower house prices, and hence poorer households, and proximity to main roads such as the M4, inner ring roads and radial roads (see the maps in **Figure 4**). Roads are a very significant source of NO_2 emissions in London.

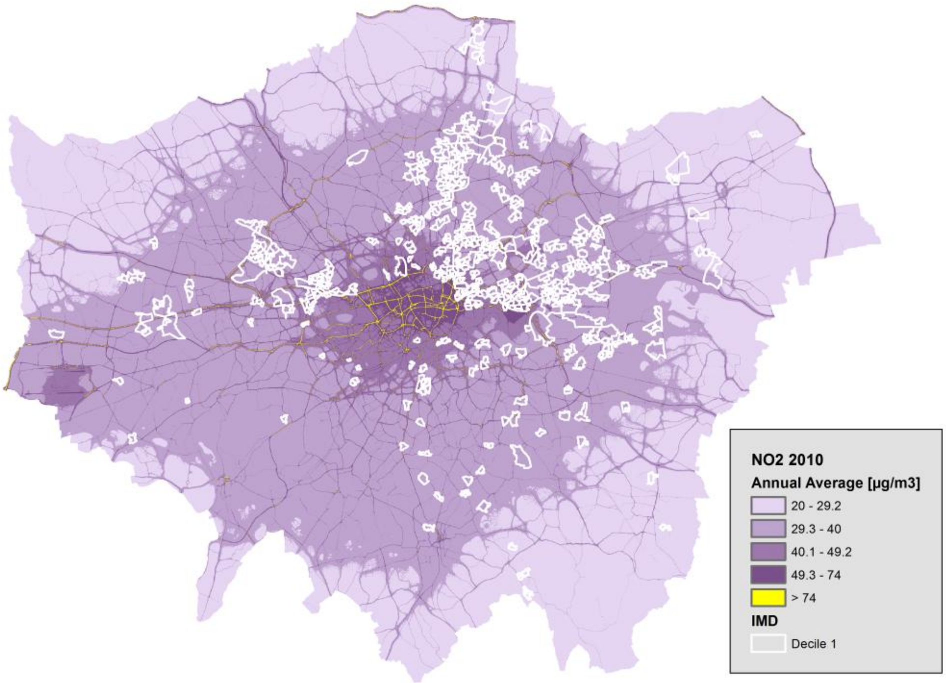
Figure 3 also shows that average concentrations of both PM_{10} and $PM_{2.5}$ vary considerably less than for NO_2 concentrations across the deprivation deciles in London because there is generally less variation in particle concentrations across the city. Furthermore there is less variation within the deprivation deciles for both PM_{10} and $PM_{2.5}$ and neither exceed the EU limit value for the annual average. However it is important to acknowledge that there were exceedences of the EU limit value for daily PM_{10} in 2010.

London's worst air quality areas can be identified as the top 10% of LSOAs in terms of average NO_2 concentration. **Table 2** shows the number of people living in these areas of worst air quality and their distribution across the deprivation deciles. It can be seen that in general there are more people in these poor air quality areas in the most deprived deciles than the least deprived deciles, and this is clearer in Inner London than Outer London.

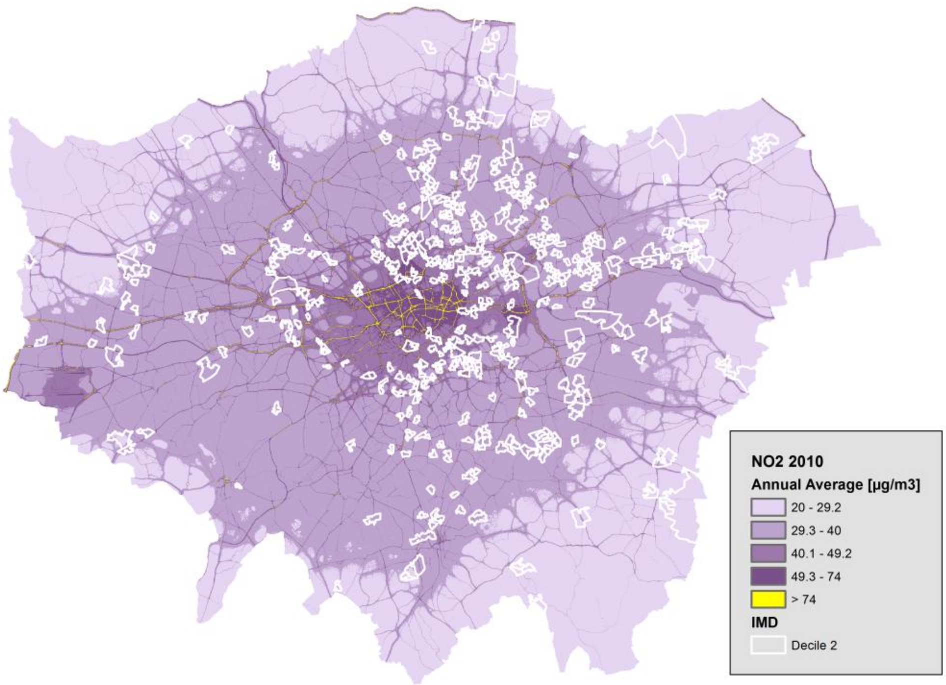
Table 3 shows the distribution of the population of these worst air quality areas across the deprivation deciles by Local Authority. Newham, Brent, Redbridge, Hackney and Tower Hamlets have the highest proportions of most deprived populations (top 30% deprived) in London's worst air quality areas. Tower Hamlets, Camden, Southwark, Islington and City of Westminster have the highest total numbers of people living in London's worst air quality areas. **Figure 4** shows the locations of the most and least deprived LSOAs across London overlaid on maps of NO_2 concentrations in 2010.

Figure 4 Annual average NO_2 concentrations in 2010 showing most and least deprived LSOAs

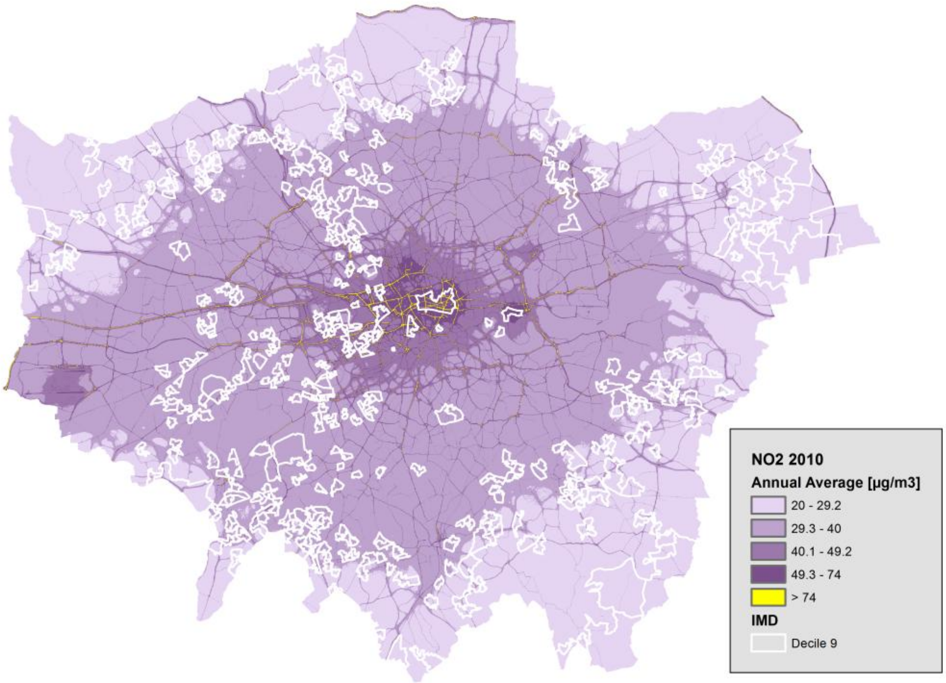
(a) locations of 10% most deprived LSOAs (Decile 1)



(b) locations of LSOAs in Deprivation Decile 2



(c) locations of LSOAs in Deprivation Decile 9



(d) locations of LSOAs in Deprivation Decile 10 (the 10% least deprived)

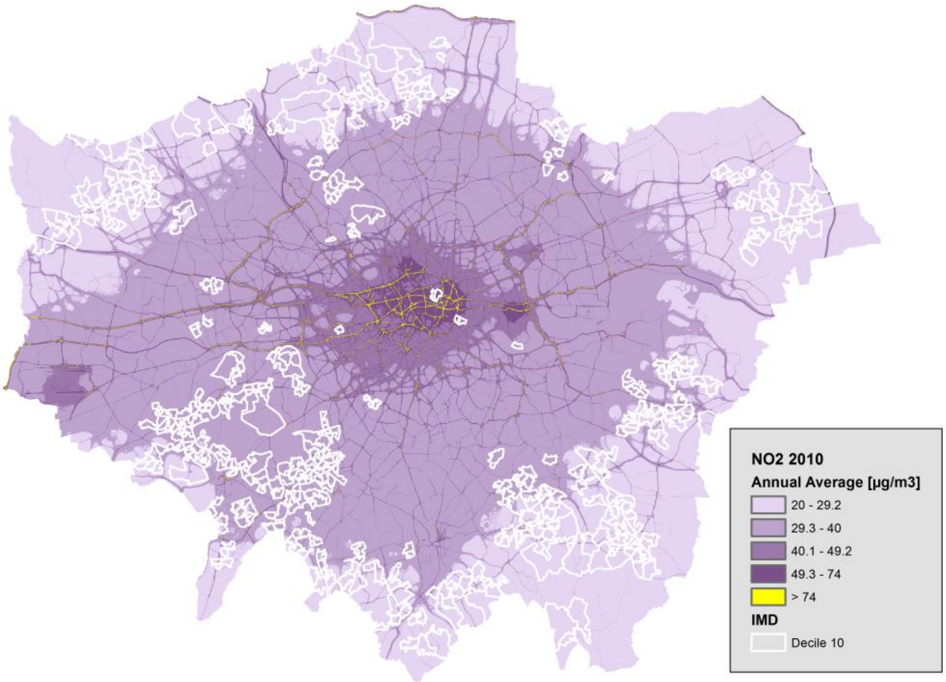


Table 2 Populations by deprivation decile in the 10% most polluted LSOAs in 2010

	Population								
	NO_2			PM_{10}			$PM_{2.5}$		
Deprivation Decile	Inner	Outer	Total	Inner	Outer	Total	Inner	Outer	Total
Decile 1 - most deprived	128,575	5,471	134,046	134,120	3,122	137,242	138,320	1,552	139,872
Decile 2	108,386	0	108,386	106,534	3,022	109,556	119,633	0	119,633
Decile 3	121,232	6,776	128,008	114,087	9,619	123,706	119,298	1,744	121,042
Decile 4	90,892	3,640	94,532	94,154	4,948	99,102	95,221	2,242	97,463
Decile 5	81,252	4,481	85,733	75,763	1,596	77,359	72,575	0	72,575
Decile 6	73,618	2,971	76,589	73,520	4,662	78,182	79,197	1,311	80,508
Decile 7	78,040	0	78,040	76,603	3,514	80,117	70,969	0	70,969
Decile 8	75,342	0	75,342	68,482	1,380	69,862	74,116	0	74,116
Decile 9	50,228	1,777	52,005	43,459	3,222	46,681	49,554	1,777	51,331
Decile 10 - least deprived	8,736	0	8,736	8,736	0	8,736	8,736	0	8,736

Table 3 Percent of population in the 10% most polluted LSOAs by deprivation deciles in 2010 by Borough

	Deprivation Decile (% of population)										**Population in deciles**
Borough	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**1 to3**
Inner London	**16**	**13**	**15**	**11**	**10**	**9**	**10**	**9**	**6**	**1**	0
Camden	5	11	28	8	21	9	11	7			47,069
City of London						15		21	26	38	0
City of Westminster	7	7	6	12	7	14	17	17	12		34,249
Hackney	76	15		9							22,203
Hammersmith and Fulham	13	9	26	18	10	12	7	4			17,182
Islington	10	23	19	19	15	8	2	5			41,643
Kensington and Chelsea	13	8	3	7	9	10	6	24	20		26,287
Lambeth	4	25	34	16	7	11			4		27,816
Lewisham	49				51						1,643
Newham	91	9									11,421
Southwark	3	17	28	18	15	6	5		2	5	46,225
Tower Hamlets	49	20	10	2	1	2	13	2	2		79,170
Wandsworth		8	8	17		16	43	8			3,285
Outer London	**22**		**27**	**14**	**18**	**12**			**7**		
Brent	53		47								7,452
Ealing	12		11	18	35	23					3,003
Hounslow									100		0
Redbridge			100								1,792
Waltham Forest				100							0

4.1 Summary

It has been shown that pollution levels are on average higher in locations of highest deprivation compared with locations of lowest deprivation, and this is shown most clearly for NO_2. 51% of LSOAs within the most deprived decile have concentrations above the NO_2 EU limit value compared with 1% in decile 10 (least deprived). However there is a wide variation in pollution concentration values across the social gradient, with all deciles showing a big range between minimum and maximum values.

The pattern for particles is less pronounced showing less variation across the social gradient because of a flatter concentration pattern across London.

It is important that future measures to improve air quality are targeted to ensure that this inequality is reduced by improving the air quality in the most deprived areas. This is investigated in **Section 7** later in this report where predicted changes in exposure are considered.

5 Pollution Exposure of Children and Young People

This study has also specifically focused on the young population in London because this age group is particularly at risk given their greater susceptibility to health impact of air pollution. The total number of this age group exposed to pollution above EU limit values has been calculated for 2010. The changes in exposure of this group for future years have also been estimated by using geographically detailed population projections data. The geographical distribution of places with high and low percentage of young people in the resident population has been considered to understand the reasons for variations in exposure. Furthermore, in order to analyse the situation specifically of deprived young children, exposure at primary schools has been considered, analysing free school meals data to indicate deprivation of their communities.

5.1 Under 19 age group

The study has estimated that in London 484,000 people under 19 are currently living in LSOAs that exceed the EU limit value of 40 $\mu g/m^3$ (**Table 4**). The majority of these young people are living in Inner London. Exposure is predicted to reduce to 53,000 in London by 2020, based on LSOA population estimates derived from ward level population projections. Furthermore, by considering the maximum modelled concentration of NO_2 within each LSOA it has been estimated that a further 1.3 million people under the age of 19 are living in close proximity to locations that exceed the EU limit value.

Table 4 Total Exposure of the Under 19 population to NO_2 Concentrations in exceedence of the EU Air Quality Objective

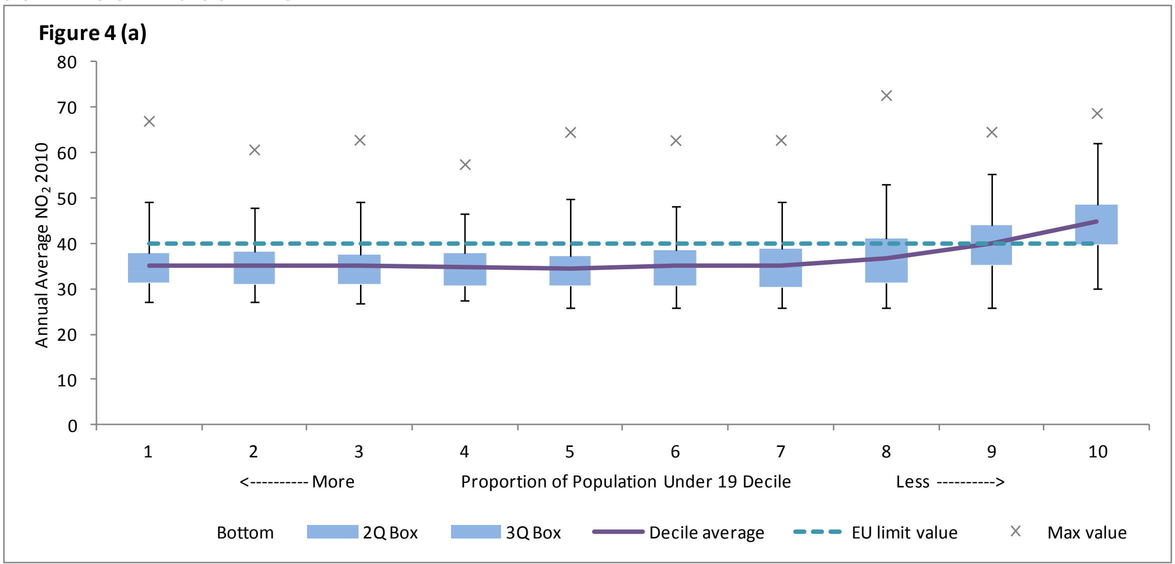
	Population under 19		
Year	Inner London	Outer London	London Total
2010	410,000	74,000	484,000
2015	193,000	16,000	209,000
2020	53,000	0	53,000

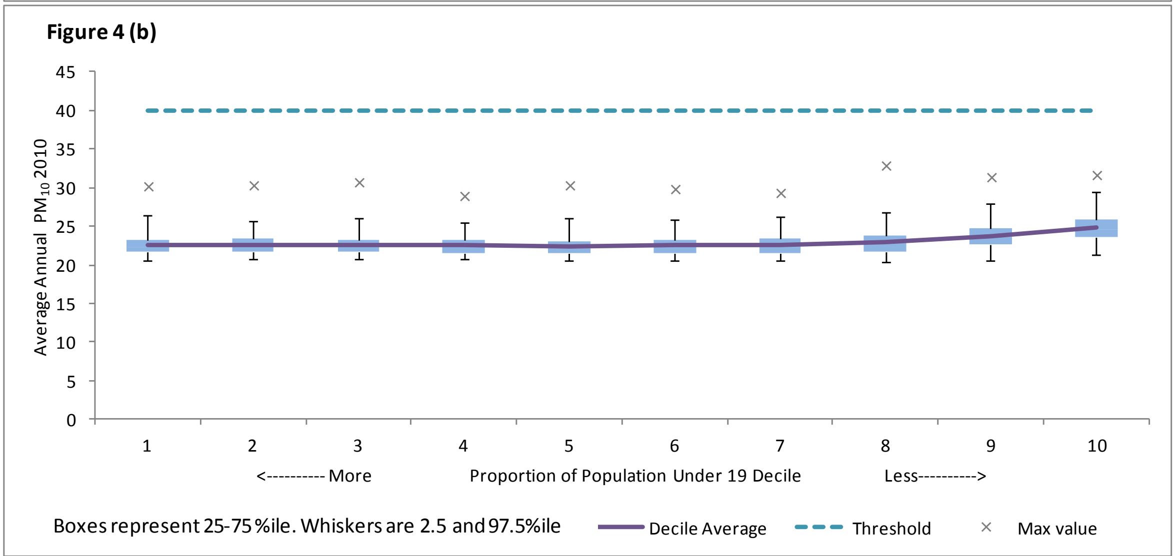
Figure 5 illustrates the trend in the average of NO_2 concentration levels across the groups of LSOAs classified by their percentage of population under 19 (henceforth called the 'under 19' deciles). The graphs also show the variability in concentrations that exists within each under 19 decile. **Figure 5** shows that under 19 decile 1 (LSOAs containing the highest proportion of under 19 year olds) is exposed to the lowest average level of NO_2 concentration. Average concentration levels of NO_2 are highest (average of 44.7 $\mu g/m^3$) in the decile with the lowest percentage of under 19 year olds. The variability in average NO_2 concentration levels in the LSOAs increases as the proportion of under 19s in LSOAs decreases, but there is again no trend in maximum values compared with percentage of under 19 in the population.

Figure 5 shows that the average concentrations of both PM_{10} and $PM_{2.5}$ vary considerably less than for NO_2 concentrations across the under 19 population deciles in London because there is generally less variation in PM concentrations across the city. Furthermore there is less variation within concentration levels in the under 19 population deciles for both PM_{10} and $PM_{2.5}$ and concentrations never exceed the EU Limit Values.

The graphs in **Figure 3** show that there is very little variation in pollution levels across the population age spectrum, with the exception that areas with the lowest proportion of young population have higher exposure levels. The maps in **Figure 6** help to explain this distribution, showing that the LSOAs in deciles 1 and 2 (high percentage of people under 19) tend to be mainly outside the most central areas of London but fairly evenly distributed. LSOAs in Under 19 Decile 10 tend to be in Inner London.

Figure 5 Pollution concentrations by decile groups of LSOAs categorised by % population under 19 in 2010 (a) NO_2, (b) PM_{10}, (c) $PM_{2.5}$





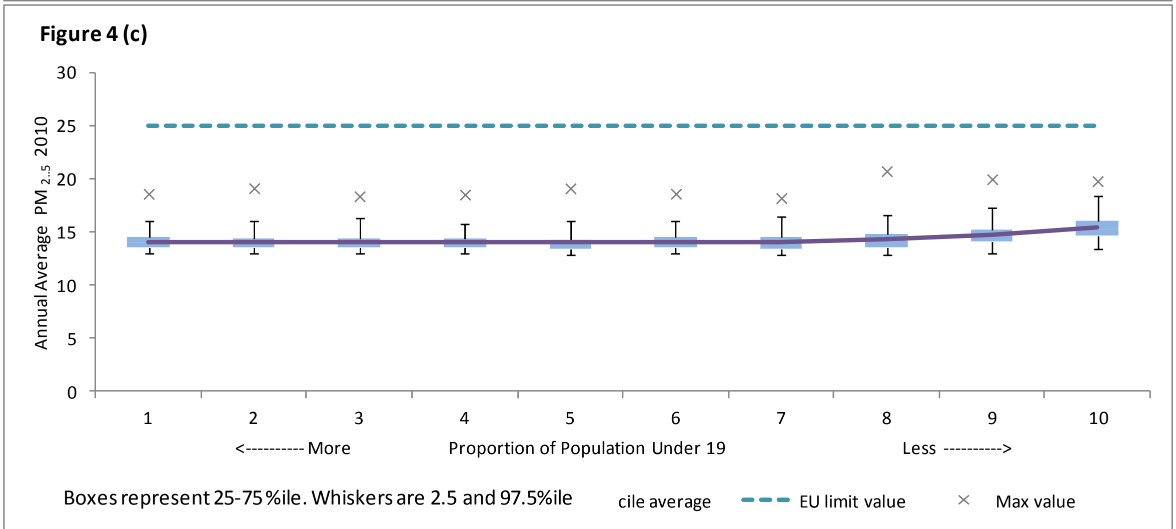
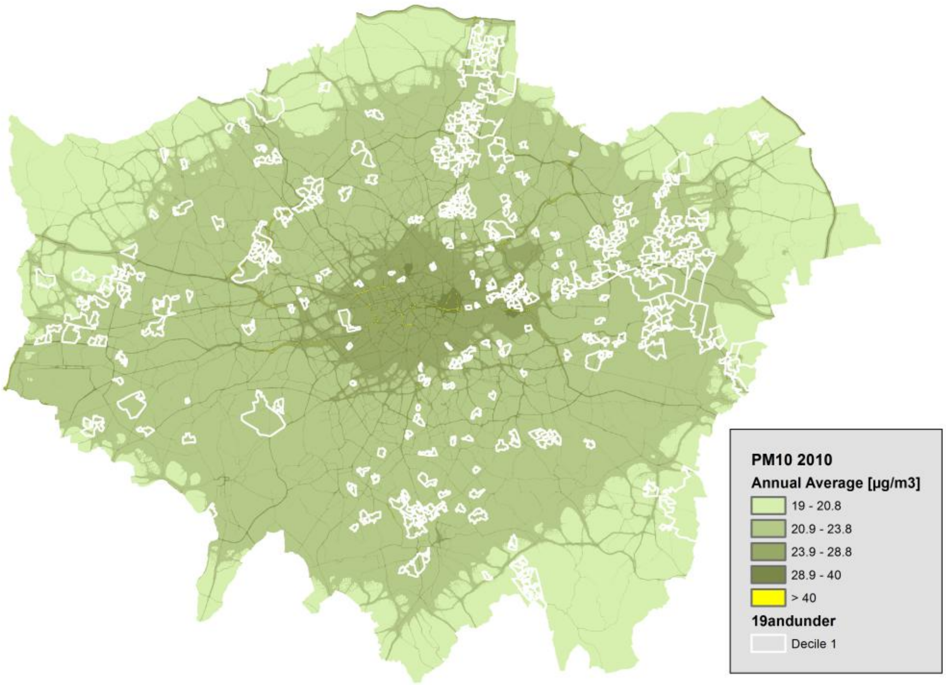
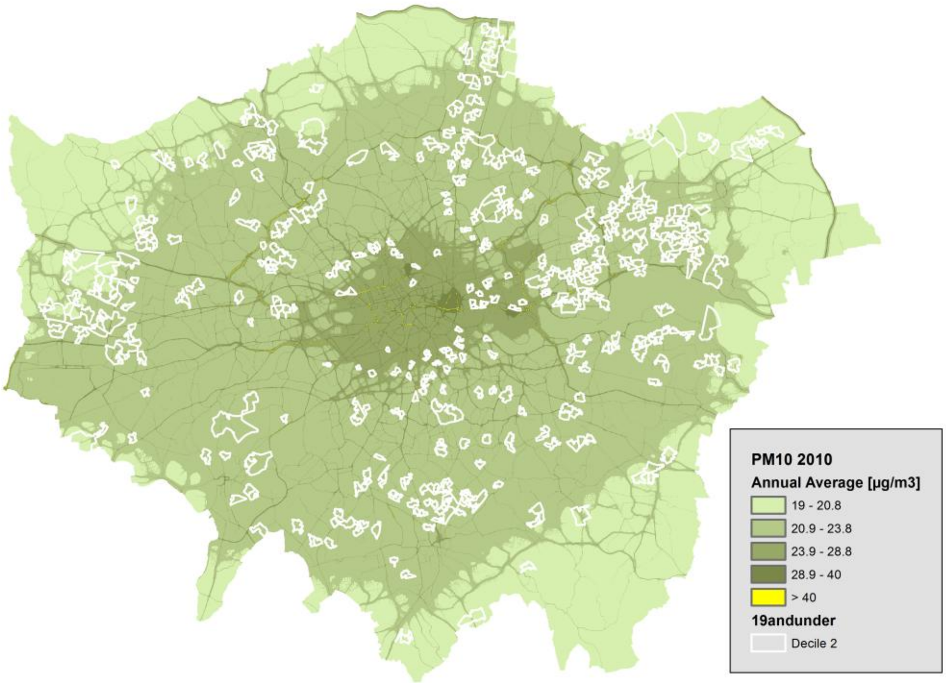


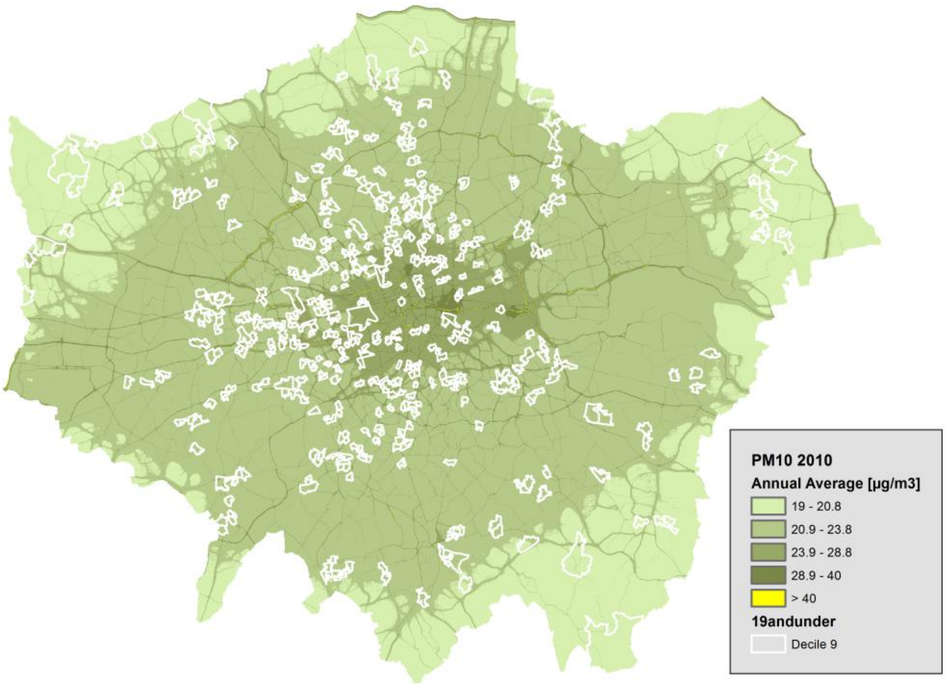
Figure 6 Annual average PM_{10} concentrations in 2010 showing LSOAs with most and least people under 19
(a) locations of LSOAs with 10% highest proportions of people under 19 (Decile 1)



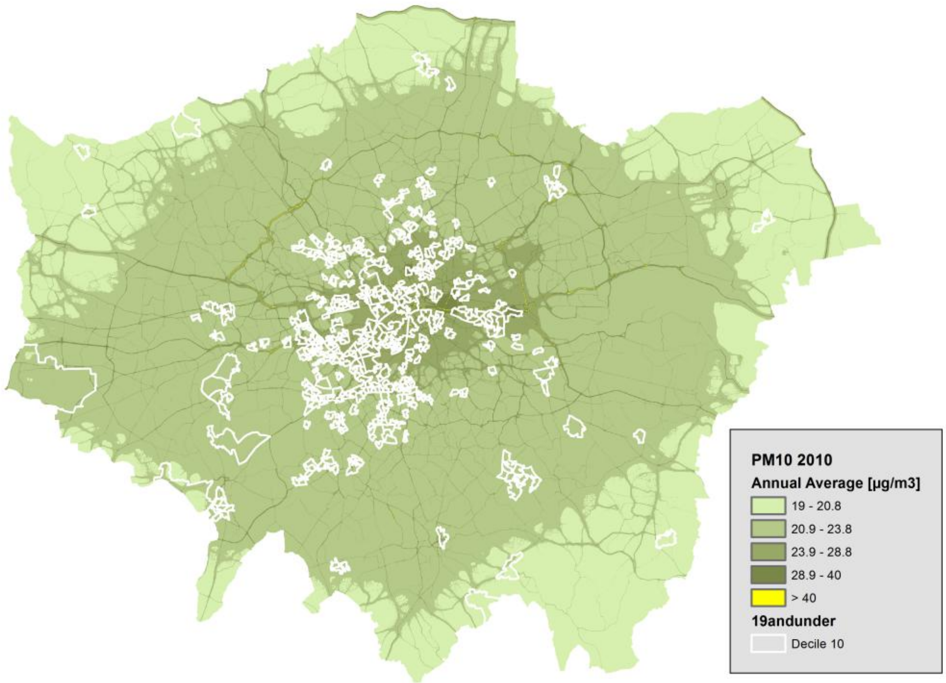
(b) locations of LSOAs in Under 19 Decile 2



(c) locations of LSOAs in Under 19 Decile 9



(d) locations of LSOAs in Under 19 Decile 10 (the 10% of LSOAs with lowest proportion of people under 19)



The number of LSOAs in each under 19 decile which have the 10% the highest NO_2 concentrations has been summed so as to show the distribution of places with young populations within this subset of places with high levels of pollution (**Table 5)**. It is evident from **Table 5** that locations with higher proportions of the more vulnerable under 19 age group are not disproportionately exposed to high levels of air pollution concentrations. In fact the general trend shows that exposure to high concentration levels of NO_2, PM_{10} and $PM_{2.5}$ increases as the number of under 19 year olds living in an LSOA decreases. An explanation for this trend may include the desire of couples to move out from the centre of the city in order to start a family, where property prices are generally cheaper and air quality improves as illustrated for PM_{10} in **Figure 6**.

Table 5: Count of LSOAs in Under 19 deciles in the 10% most NO_2 polluted LSOAs in 2010

Population Under 19 Decile	Count of LSOAs in Pollution Decile 1 in 2010								
	NO_2			PM_{10}			$PM_{2.5}$		
	Inner	Outer	Total	Inner	Outer	Total	Inner	Outer	Total
Decile 1 - most under 19s	22	0	22	25	2	27	24	0	24
Decile 2	23	1	24	25	1	26	24	0	24
Decile 3	22	2	24	19	3	22	22	1	23
Decile 4	13	2	15	19	1	20	19	0	19
Decile 5	25	3	28	23	2	25	24	1	25
Decile 6	25	1	26	26	3	29	26	0	26
Decile 7	27	0	27	30	1	31	34	1	35
Decile 8	45	0	45	44	1	45	48	0	48
Decile 9	89	5	94	81	5	86	81	2	83
Decile 10 - least under 19s	176	2	178	172	0	172	175	1	176

In summary: in general young people are not experiencing exposure higher than the total population. However it is also important to consider specifically young deprived children to examine the pattern in that sub-group as they are particularly susceptible to air pollution impacts and therefore air quality at primary school locations is considered in the next section.

5.2 NO_2 Concentrations at Primary School Locations

Previous analysis published by the Policy Exchange[11] stated that in the worst 10% of London for NO_2, 5-10 year old children were 47% more likely than the London average to be eligible for free school meals (FSM). That study also found that 320,000 children attend schools in London within 150m of roads carrying more than 10,000 vehicles per day. This is the level of traffic that has been found to increase risk of developing or exacerbating asthma in children. We have therefore considered in this study the locations of all primary schools and the proportion of children at these schools that are eligible for free school meals[12] so that we can analyse this in relation to the latest air pollution maps for London.

The free school meals (FSM) data provides a more up to date dataset than the Index of Multiple Deprivation and allows direct combination of data on children's' exposure and this indicator (as a surrogate for deprivation). Average pollution levels within a radius of 150m around each primary school were calculated from the 20m resolution annual average NO_2 maps for 2010. 24% of schools have average concentrations above the EU limit value.

Figure 7 shows the distribution of schools according to the percentage of pupils eligible for free school meals, and within this the number of schools with an annual average NO_2 concentration above the EU limit value. **Table 6** provides numeric information for the same dataset. This clearly shows that there is a link between levels of exceedence and the proportion of pupils attending a school who have free school meals. A deprived school can be defined as one with more than 40%

[11] Something in the Air, Policy Exchange 2012. http://www.policyexchange.org.uk/publications/category/item/something-in-the-air-the-forgotten-crisis-of-britain-s-poor-air-quality

[12] School league table data for 2012 published by The Guardian stating for each school the percent of pupils eligible for Free School Meals (FSM) in last 6 years or looked after continuously for 6 months http://www.guardian.co.uk/news/datablog/2012/dec/13/primary-school-league-tables-2012-data#data

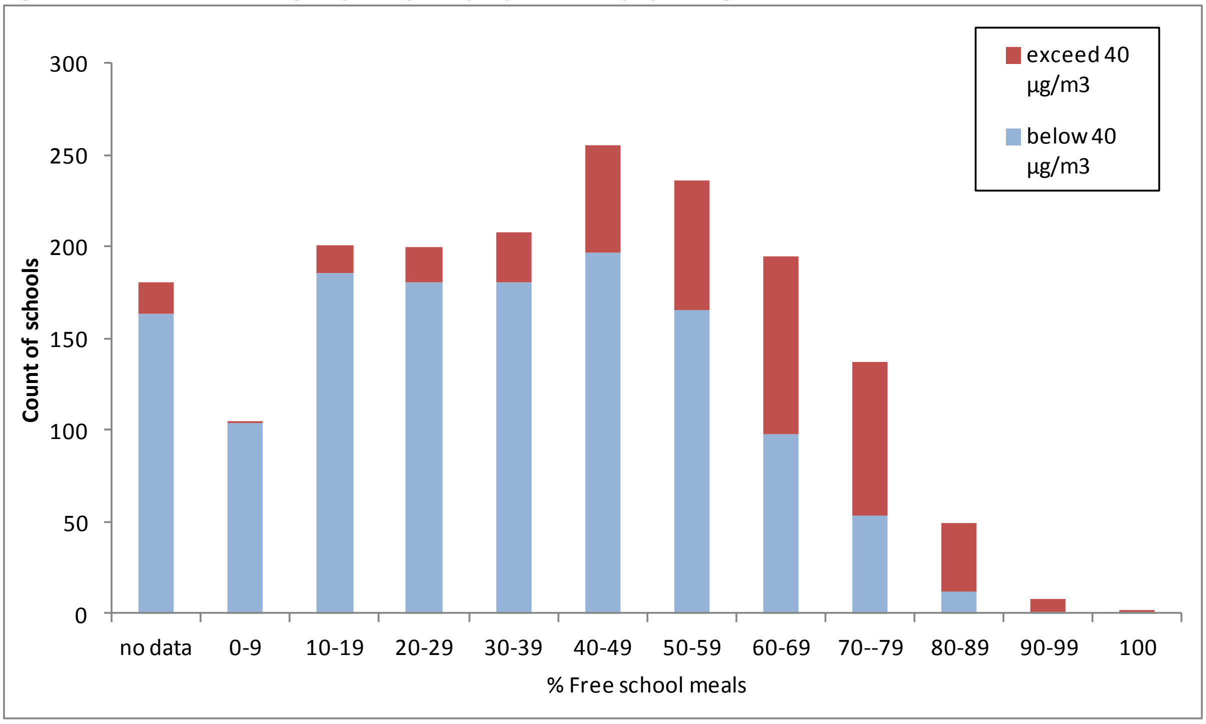
pupils eligible for free school meals. In 2010, there were 1777 primary schools in London of which 433 were in locations where average concentrations exceed the NO_2 EU limit value. Of these 433 primary schools, 82% were deprived schools. By contrast, of the 1344 primary schools that were not exposed to above EU limit values of NO_2, 39% were deprived. This presents evidence that there is significant disadvantage in terms of air pollution for the more deprived communities surrounding these deprived schools. The numbers of schools and pupils is predicted to significantly reduce by 2020 but there is still a disparity between deprived and non-deprived schools.

Table 6 Primary Schools and pupil counts in locations exceeding the EU limit value for NO_2

	2010	2015	2020	All primary schools (2012)
Number of primary schools exceeding NO_2 EU limit value	433	193	45	1777
percent	*24%*	*11%*	*3%*	
Number of pupils in primary schools exceeding NO_2 EU limit value	137,000	58,000	11,000	626,000
percent	*22%*	*9%*	*2%*	
Number of deprived primary schools exceeding NO_2 EU limit value	354	163	37	
Number of non-deprived schools exceeding NO_2 EU limit value	79	30	4	

Note 'deprived schools' defined as those with >40% of pupils eligible for free school meals
Figures for future years assume %FSM remain at 2012 rates

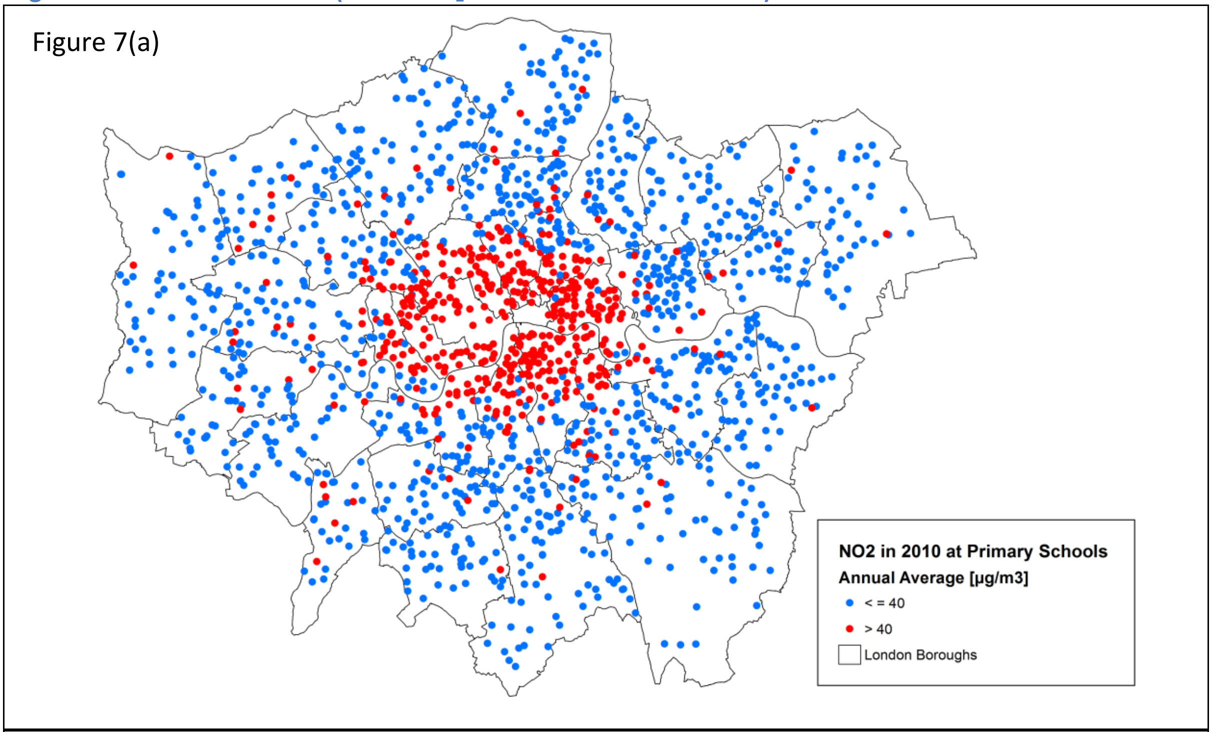
Figure 7 Count of schools grouped by the proportion of pupils eligible for FSM and an NO_2 exceedence



The maps in **Figure 8** shows that schools with average pollution levels above the EU Limit Value are predominantly in Inner London. Those in Outer London are close to main roads. Those schools with a higher proportion of pupils on free school meals are mostly located in inner London and therefore have higher levels of exposure.

Table 7 shows a list of the 20 primary schools with the highest average NO_2 concentrations in 2010.

Figure 8 Primary schools categorised by (a) average NO_2 concentration 2010 and (b) percent of pupils eligible for Free School Meals (where NO_2 is above the EU limit value)



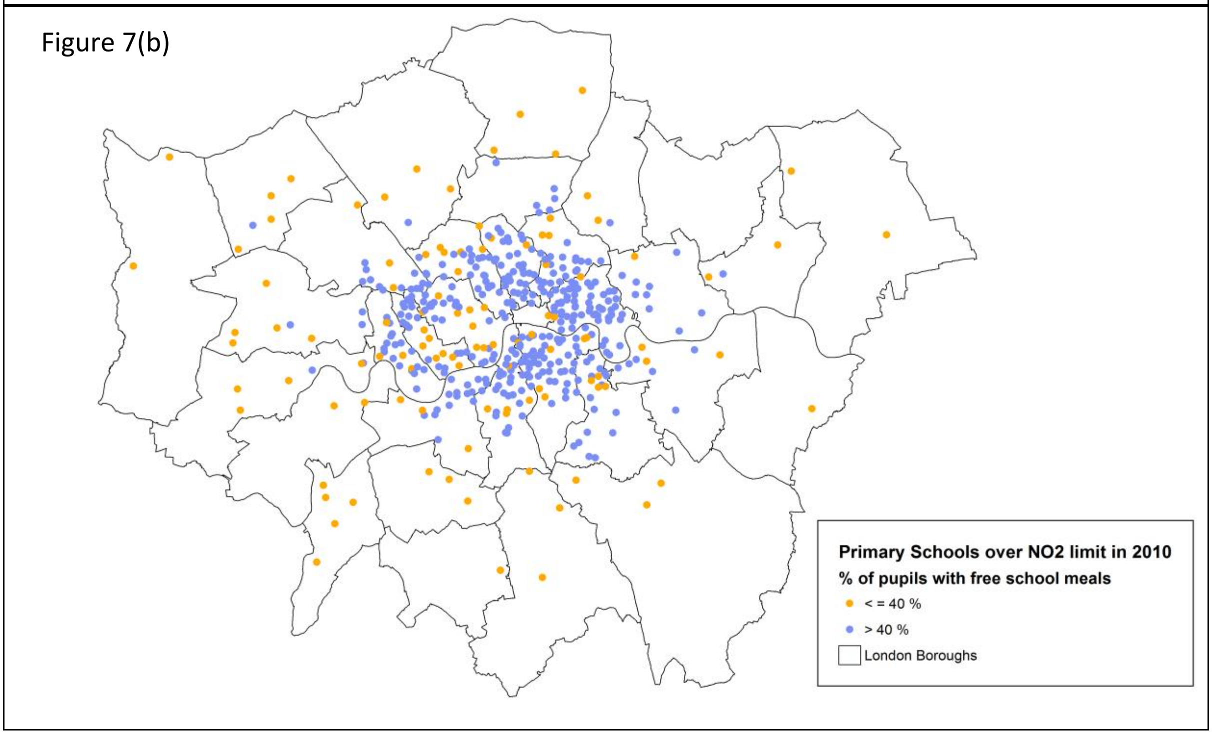


Table 7 Top 20 schools with the highest average NO_2 concentration within 150m of the school

School Name	Borough	Average NO_2 concentration 2010 (µg/m3)	Number of pupils	Percent FSM
Sir John Cass's Foundation Primary School	City of London	73.5	232	20%
Canon Barnett Primary School	Tower Hamlets	69.2	274	76%
English Martyrs Roman Catholic Primary School	Tower Hamlets	68.8	221	32%
Woolmore Primary School	Tower Hamlets	66.4	250	73%
St Clement Danes CofE Primary School	Westminster	65.6	215	45%
St George's Cathedral Catholic Primary School	Southwark	64.8	335	39%
St Paul's CofE Primary School	Hammersmith and Fulham	64.2	235	50%
St Mary's Bryanston Square CofE School	Westminster	63.8	240	63%
Argyle Primary School	Camden	63.1	420	70%
St Peter's Eaton Square CofE Primary School	Westminster	62.5	288	15%
Holy Family Catholic School	Tower Hamlets	61.6	244	69%
Tower Bridge Primary School	Southwark	61.6	207	70%
St John Evangelist RC Primary School	Islington	60.9	295	66%
Christ Church Bentinck CofE Primary School	Westminster	60.8	267	83%
St Joseph's Catholic Primary School	Southwark	60.6	229	48%
Copenhagen Primary School	Islington	60.5	228	80%
St Vincent de Paul RC Primary School	Westminster	60.2	249	16%
Winton Primary School	Islington	59.9	216	65%
The Cathedral School of St Saviour and St Mary Overy	Southwark	59.2	223	25%
Blessed Sacrament RC Primary School	Islington	59.0	203	58%

It is clear from the data presented above that a large number of schools were exposed to poor air quality in 2010 and that action is required to reduce exposure of children at these locations. The Cleaner Air 4 Schools programme[13] is a proactive approach to improve air quality through education and behaviour change. In combination with other plans and measures to reduce pollution, we recommend that this scheme should be expanded to cover more schools particularly focusing on those in deprived areas.

[13] Cleaner Air 4 Schools http://www.lsx.org.uk/whatwedo/CleanAir4Schools_page3504.aspx

6 Exposure in the Over 65 Age Group

It has been estimated that in London 194,000 people over 65 are currently living in LSOAs that exceed the annual NO_2 EU limit value of 40 µg/m^3 (**Table 8**). The majority of these older people are located in inner London. Exposure at this level is predicted to reduce to 26,000 in London by 2020. Furthermore, by considering the maximum modelled concentration of NO_2 within each LSOA it has been estimated that a further 600,000 people over 65 are living in close proximity to locations that exceed the EU limit value.

Table 8 Total Exposure of the Over 65 population to NO_2 Concentrations in exceedence of the EU Air Quality Objective

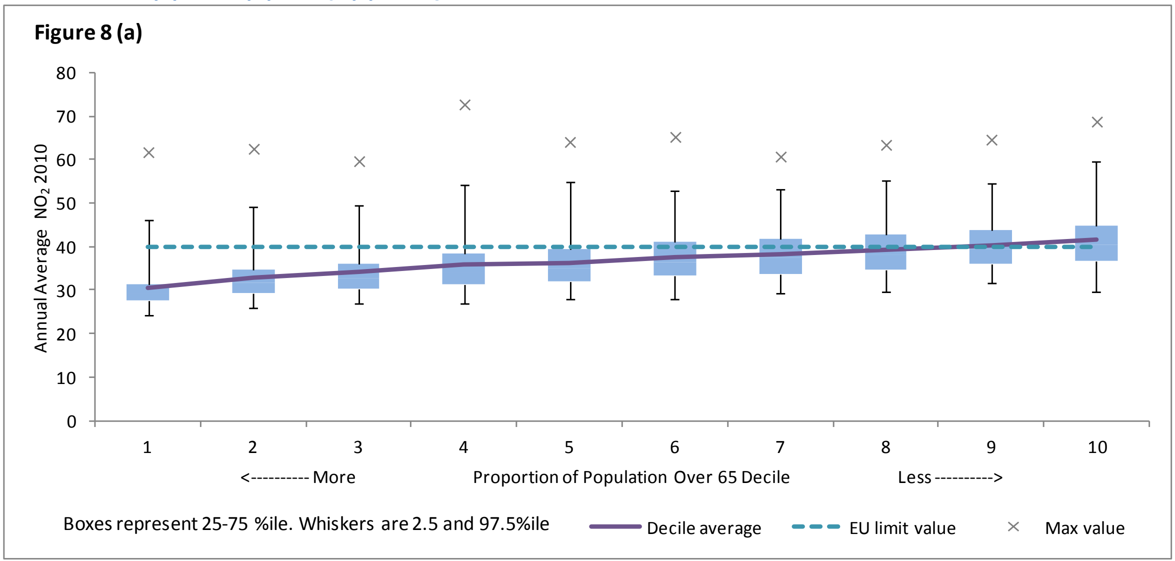
	Population over 65		
Year	Inner London	Outer London	London Total
2010	165,000	28,000	193,000
2015	90,000	6,000	96,000
2020	26,000	0	26,000

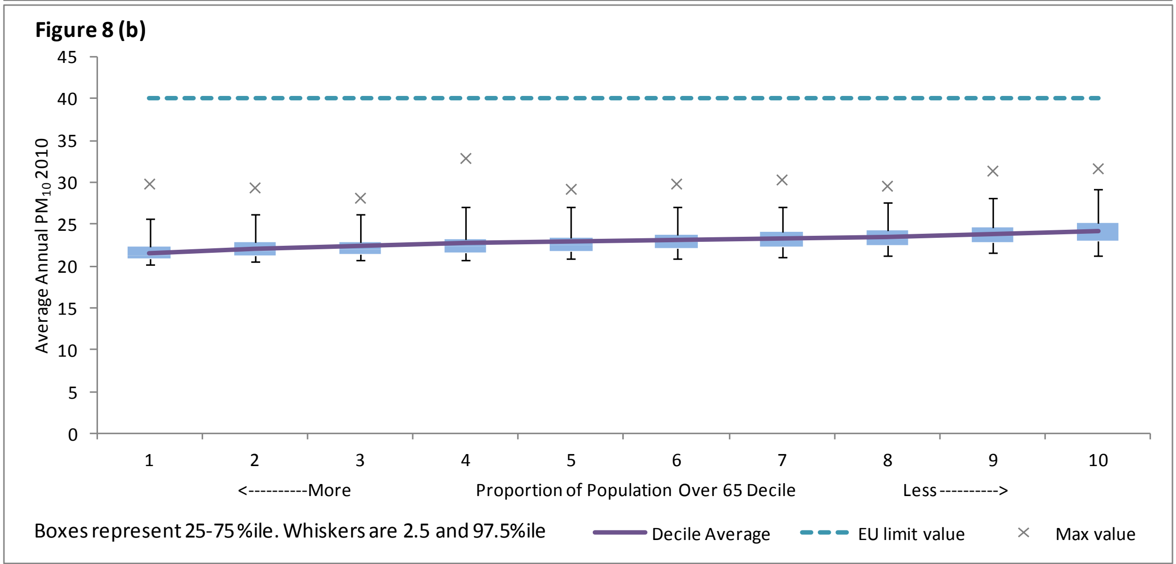
Figure 9 illustrates the trend in the average of NO_2 concentration levels across the groups of LSOAs classified by their percentage of population over 65 (henceforth called the 'over 65' deciles). The graphs also show the variability in concentration that exists within each over 65 decile. **Figure 9** also shows that over 65 decile 1 (LSOAs containing the highest proportion of over 65 year olds) is exposed to the lowest average level of NO_2 concentration. Average concentration levels of NO_2 are highest (average of 41.5 µg/m^3) in the decile with the lowest percentage of over 65 year olds and lowest in the decile with highest proportion of over 65s. The variability in average NO_2 concentration levels in the LSOAs increases as the proportion of over 65 in LSOAs decreases, but there is again no trend in maximum values compared with percentage of under 19 in the population.

It is however interesting to note that places with a high proportion of over 65s benefit from lower levels of NO_2 on average, compared with a very flat average concentration across the deciles for under 19s.

Figure 9 also shows that the average trend in concentrations of both PM_{10} and $PM_{2.5}$ vary considerably less than for NO_2 concentrations across the over 65 population deciles in London. This reflects the fact that the sources of PM emissions are more varied than NO_2 emissions and the relationship between population age groups and concentration levels is therefore less strong. Furthermore there is less variation within the over 65 population deciles for both PM_{10} and $PM_{2.5}$ and the annual average thresholds set in the EU Air Quality Directive are not exceeded.

Figure 9 Pollution concentrations by decile groups of LSOAs categorised by % population over 65 decile London 2010 (a) NO_2, (b) PM_{10}, (c) $PM_{2.5}$





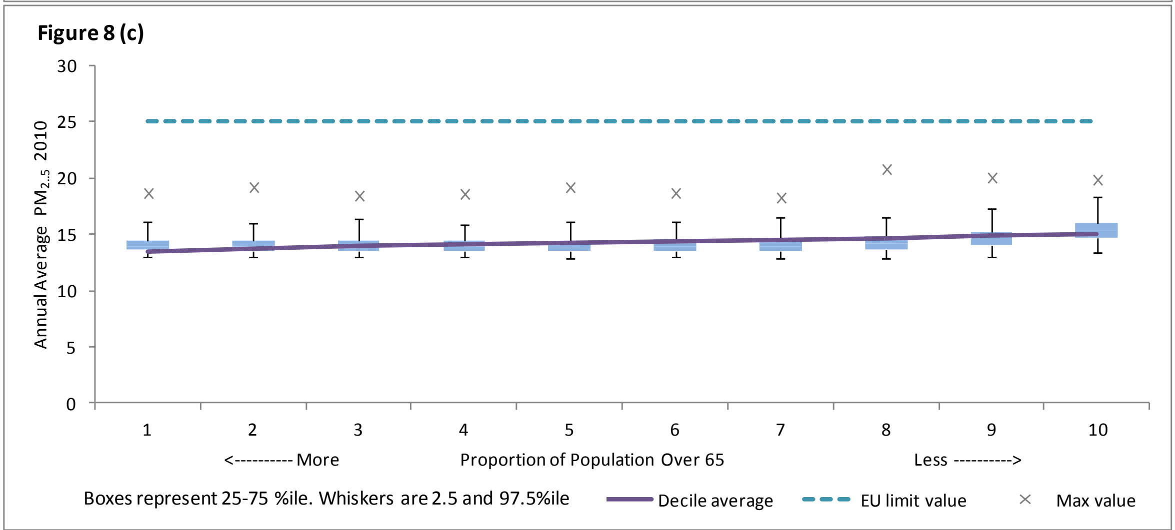
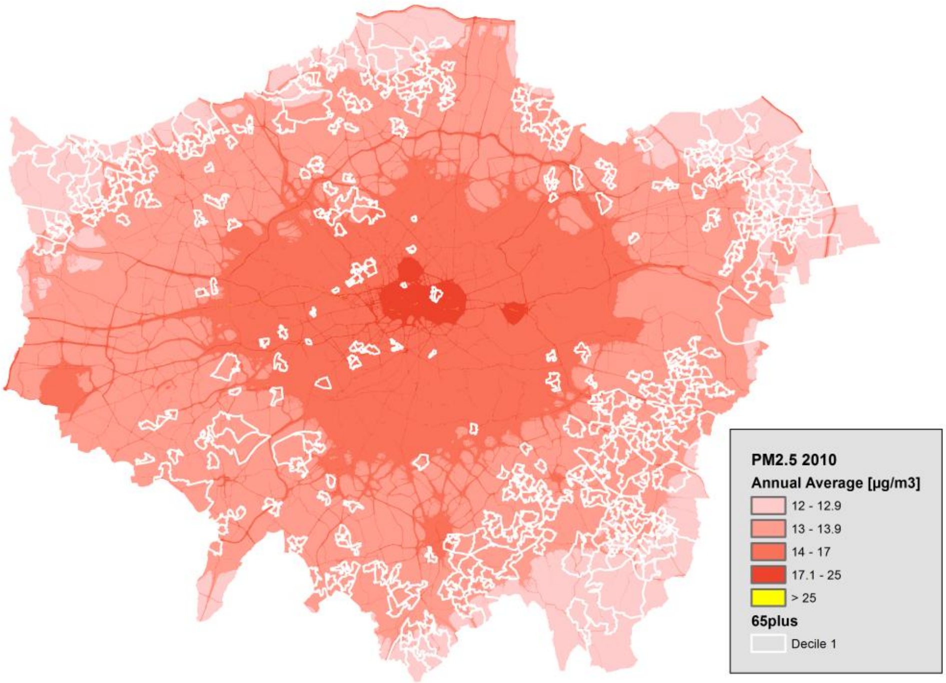
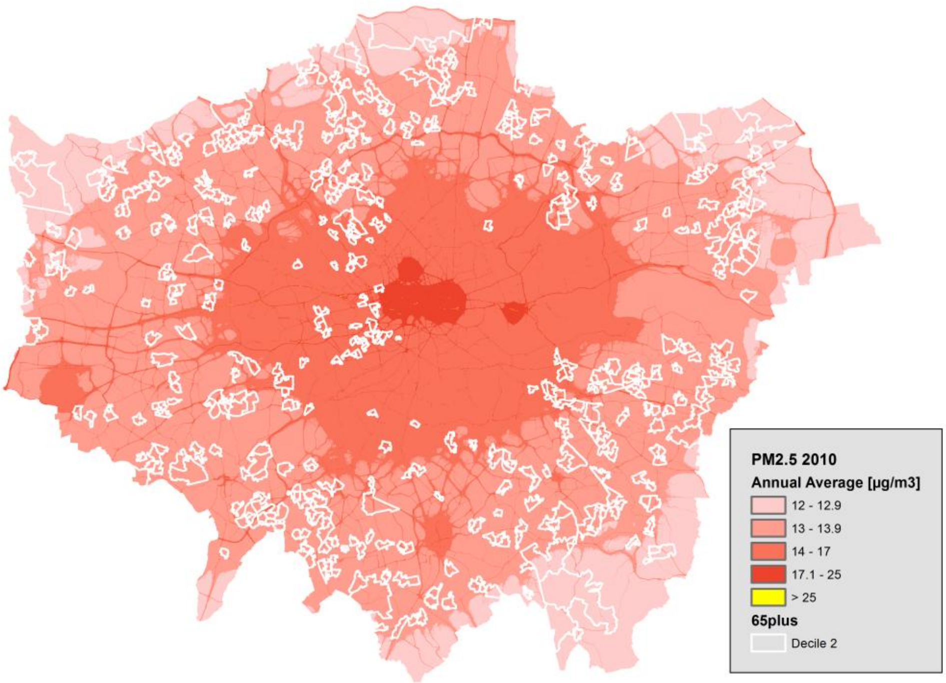


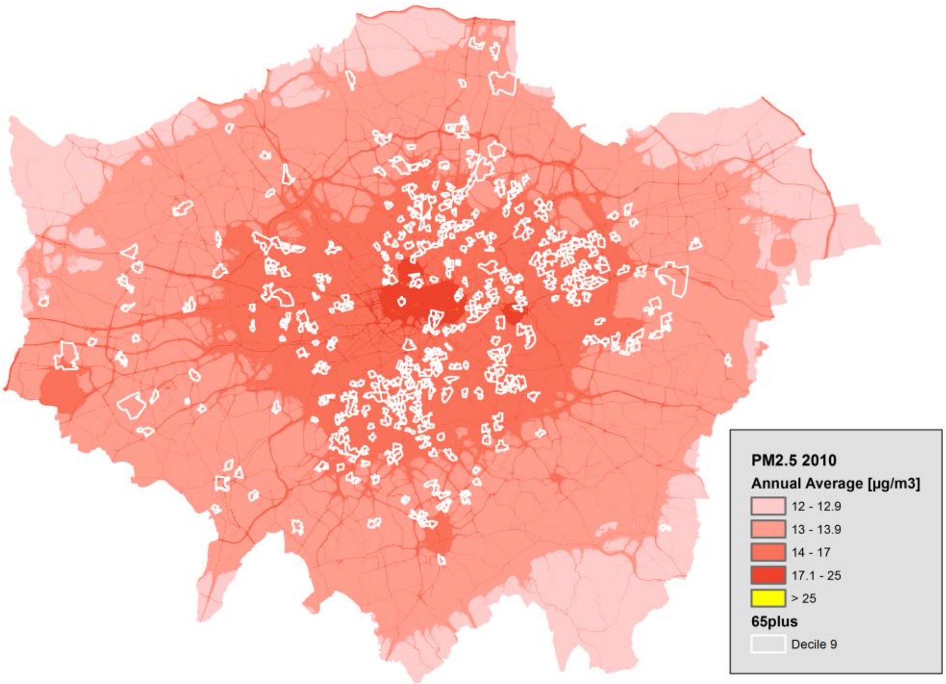
Figure 10 Annual average $PM_{2.5}$ concentrations in 2010 showing LSOAs with most and least people over 65
(a) locations of LSOAs with 10% highest proportions of people over 65 (Decile 1)



(b) locations of LSOAs in Over 65 Decile 2



(c) locations of LSOAs in Over 65 Decile 9



(d) locations of LSOAs in Over 65 Decile 10 (the 10% of LSOAs with lowest proportion of people over 65)

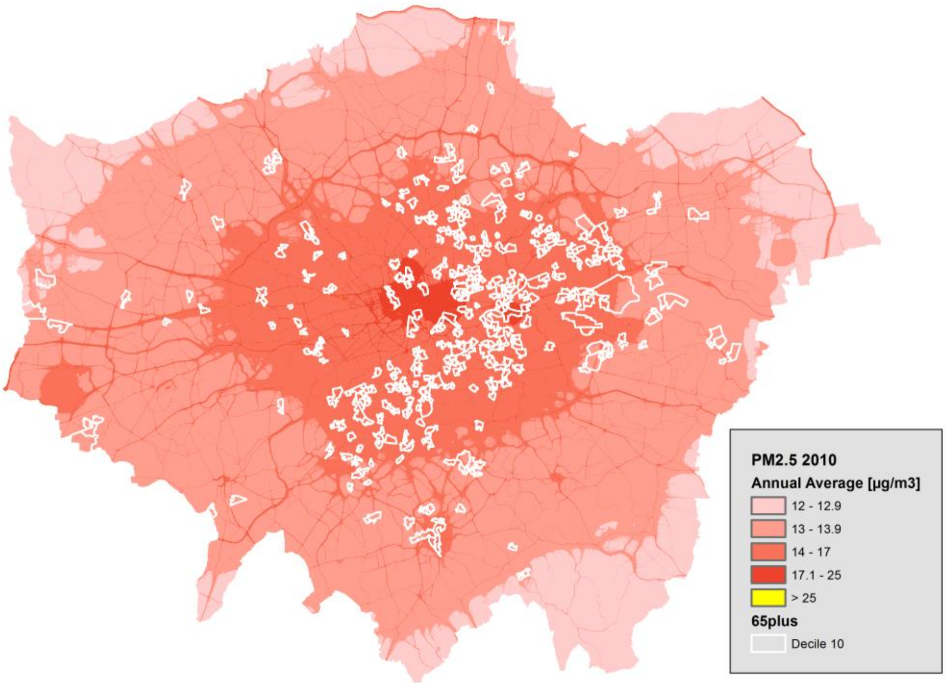


Table 9 shows the number of LSOAs within each over 65 year decile which have the highest 10% concentration levels of NO_2, PM_{10} and $PM_{2.5}$.

Table 9 Count of LSOAs in Over 65 deciles in the 10% most NO_2 polluted LSOAs in 2010

Population Over 65 Decile	Number of LSOAs in Pollution Decile 1 in 2010								
	NO_2			PM_{10}			$PM_{2.5}$		
	Inner	Outer	Total	Inner	Outer	Total	Inner	Outer	Total
Decile 1 - most over 65s	14	0	14	13	0	13	16	0	16
Decile 2	27	0	27	21	2	23	22	0	22
Decile 3	27	1	28	23	2	25	23	2	25
Decile 4	39	2	41	40	2	42	40	1	41
Decile 5	38	0	38	40	2	42	42	0	42
Decile 6	49	1	50	48	1	49	48	0	48
Decile 7	46	3	49	41	4	45	47	1	48
Decile 8	61	1	62	65	0	65	64	1	65
Decile 9	67	4	71	65	4	69	71	0	71
Decile 10 - least over 65s	99	4	103	108	2	110	104	1	105

In summary, the data shows that the more vulnerable over 65 age group is not disproportionately exposed to high levels of air pollution concentrations. In fact the general trend shows that exposure to high concentration levels of NO_2, PM_{10} and $PM_{2.5}$ decreases as the number of over 65 year olds living in an LSOA increases. This is further illustrated by the maps in **Figure 10**.

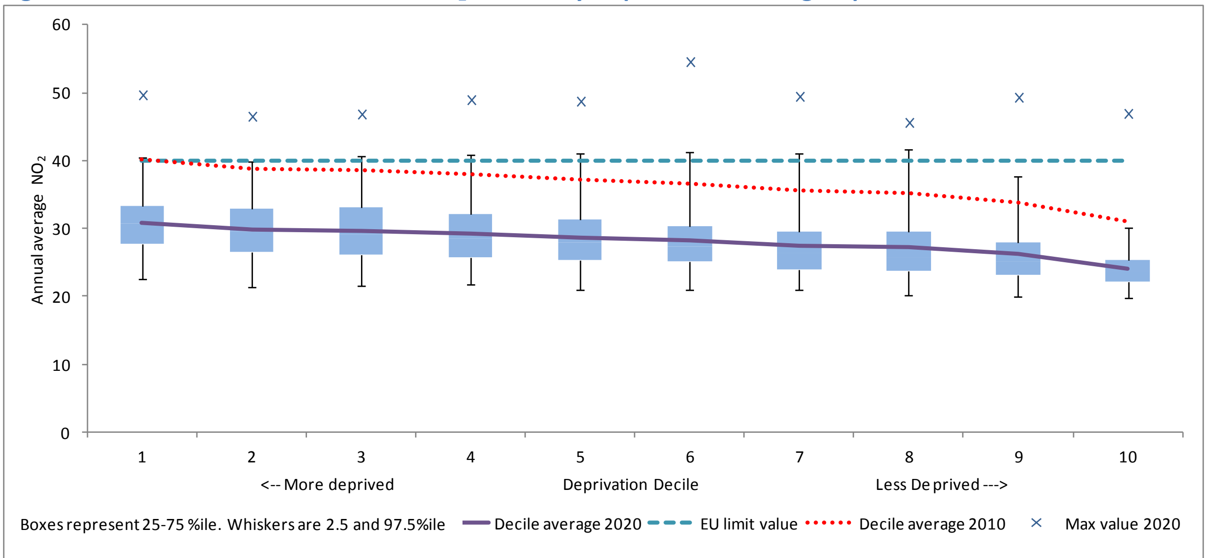
7 Predicted changes in exposure by 2020

7.1 Changes in exposure

Estimates have been presented earlier (**Figure 1**) of the change between 2008 and 2020 in population exposure to concentrations of NO_2 above the EU limit value. The number of people exposed decreases by 86 % in this time period but by 2020 over 300,000 people are predicted to still live in locations with average concentrations above the EU limit value.

Figure 11 shows the predicted exposure to NO_2 across the social gradient in London based on modelled 2020 concentrations compared with the 2010 IMD dataset. In contrast to the average NO_2 concentrations by decile in 2010 (the red dotted line, and which was also presented in **Figure 3a**), decile average values for 2020 are expected to decline across all the deprivation deciles so that on average by decile concentrations are below the EU limit value 40 µg/m^3 limit for NO_2 concentrations. However, this average hides large ranges of concentrations across each decile, shown by the 2.5 to 97.5 percentiles and maximum values plotted in **Figure 11**. The reduction in the decile average concentration between 2010 and 2020 is biggest in decile 1 (most deprived locations) and therefore the amount of inequality across the social gradient is reducing with time resulting in a flatter average across the deciles.

Figure 11 Pollution concentrations of NO_2 in 2020 by Deprivation decile groups of LSOAs in London 2020



7.2 Changes in NO_2 from different sources

In order to further analyse the changes in NO_2 concentrations, contributions of NO_X from different sources for 2010 and 2020, split into road transport and other sources, have been provided by the ERG modellers. These have been converted to NO_2 in order to make the data comparable to the total NO_2 data already presented[14]. This source apportionment enables a simple assessment of the components of change in average NO_2 concentrations between 2010 and 2020. This is shown

[14] An empirical approach was used to calculate the annual mean NO_2 concentrations from the NO_x concentration source apportionment data provided by Kings College. The empirical approach involved the conversion of NO_x concentrations into both primary and background NO_2 in order to account for the different NO_x to NO_2 ratios associated with each source of NO_x. In order to ensure consistency, the conversion of the NO_x sources to NO_2 are subsequently scaled up to match the total NO_2 concentration provided by ERG.

in **Figure 12**. Road transport sources contribute the most significant change across this timeframe and it is reductions in this source that help to reduce the exposure of the most deprived populations.

Figure 12 Pollution concentrations in 2020 by Deprivation decile groups of LSOAs in London 2020 (a) NO_2 originating from road transport sources, (b) NO_2 originating from other sources

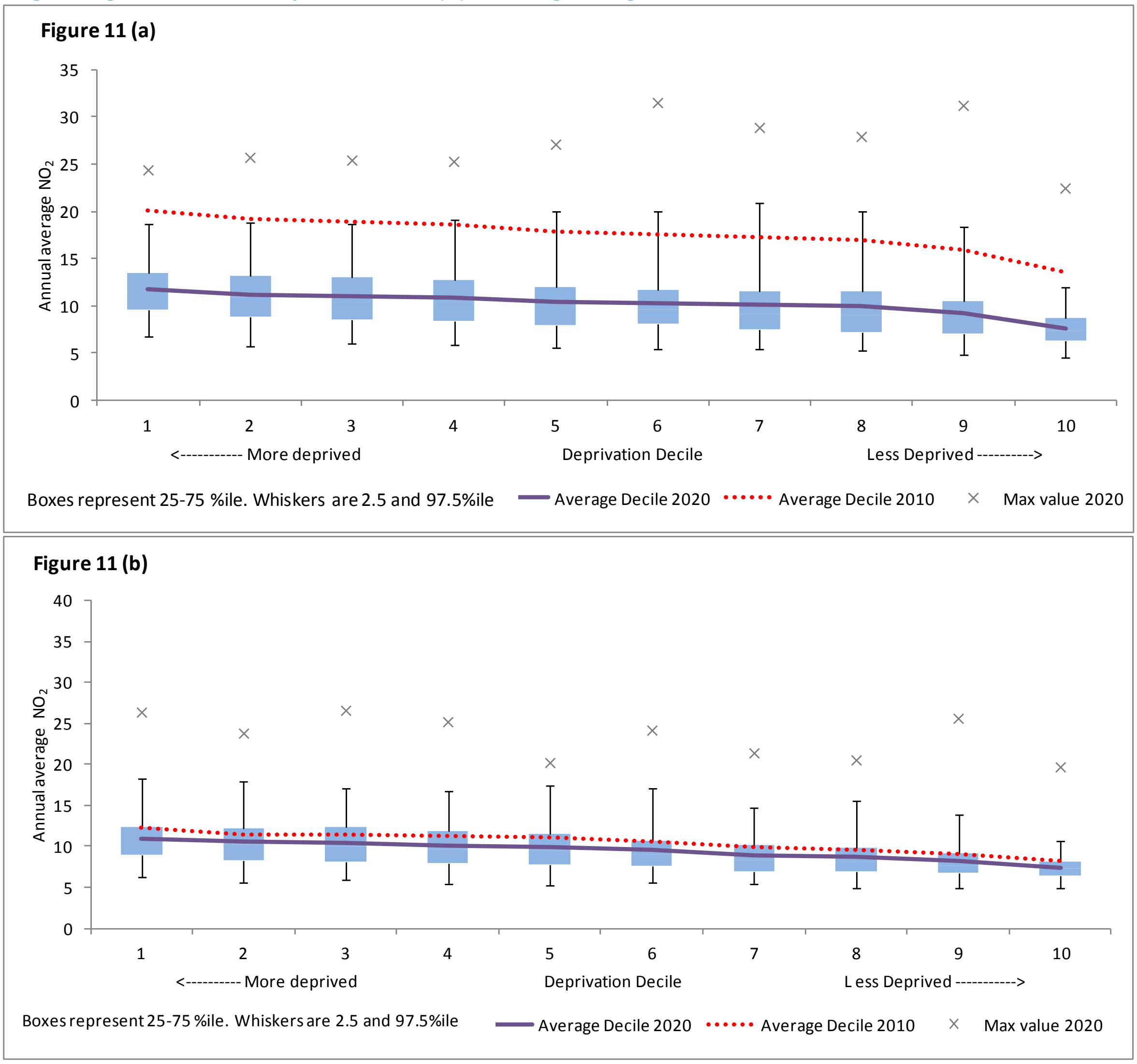
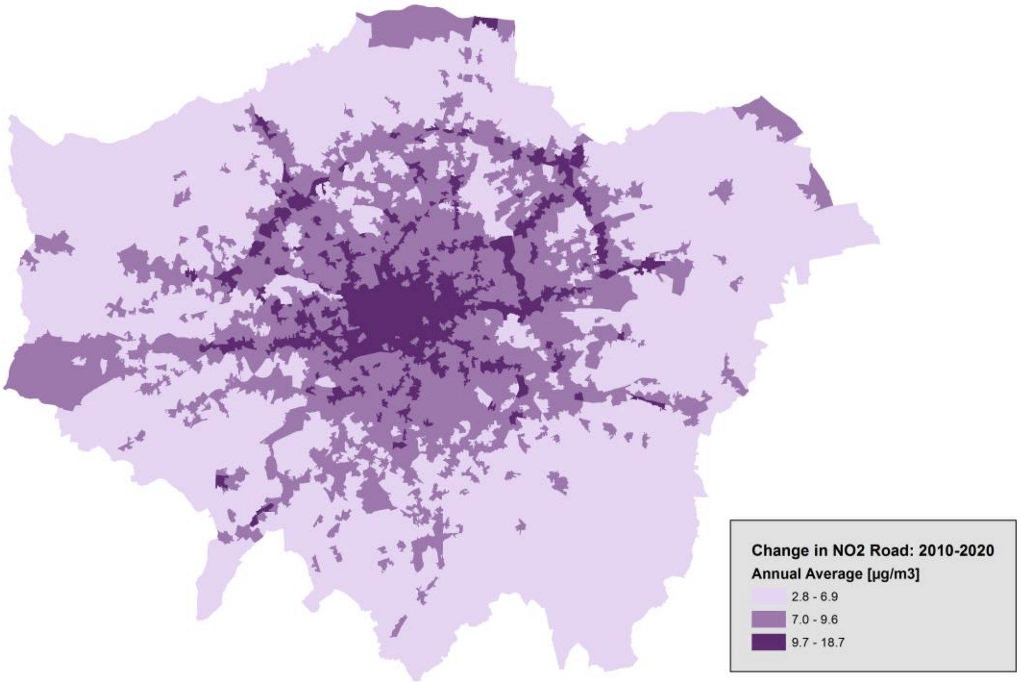
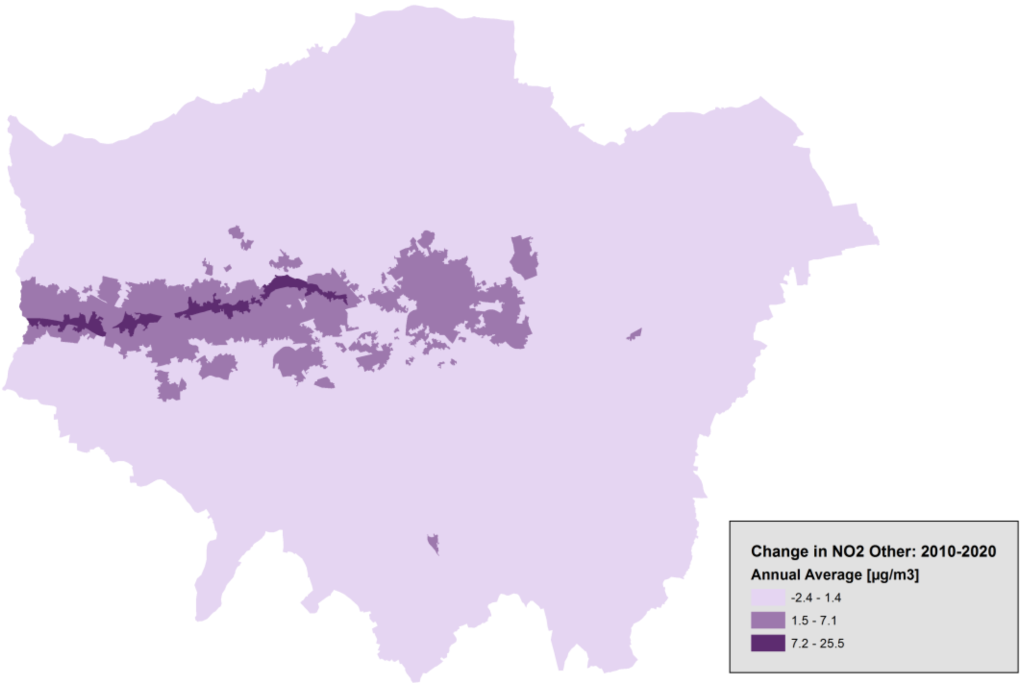


Figure 13 shows the locations of the changes between 2010 and 2020 in NO_2 concentrations attributed to these separate sources, presented as change in average concentration within LSOAs. For road transport this shows the importance of the radial and inner ring roads, the central London area but also traffic around Heathrow and the M25 where it is close to the GLA area. This reflects the assumption that fleet emission factors generally reduce across all traffic in London and therefore reductions are highest in places where traffic is currently highest. For other sources (**Figure 13b)** it highlights the big change in emissions from the Paddington rail line heading west out of London. There are also changes in non-road mobile machinery emissions, such as in Croydon and this map also shows reductions in central London related to energy efficiency in the building stock.

Figure 13 Changes in NO_2 concentration between 2010 and 2020 (a) from road sources



(b) from other sources

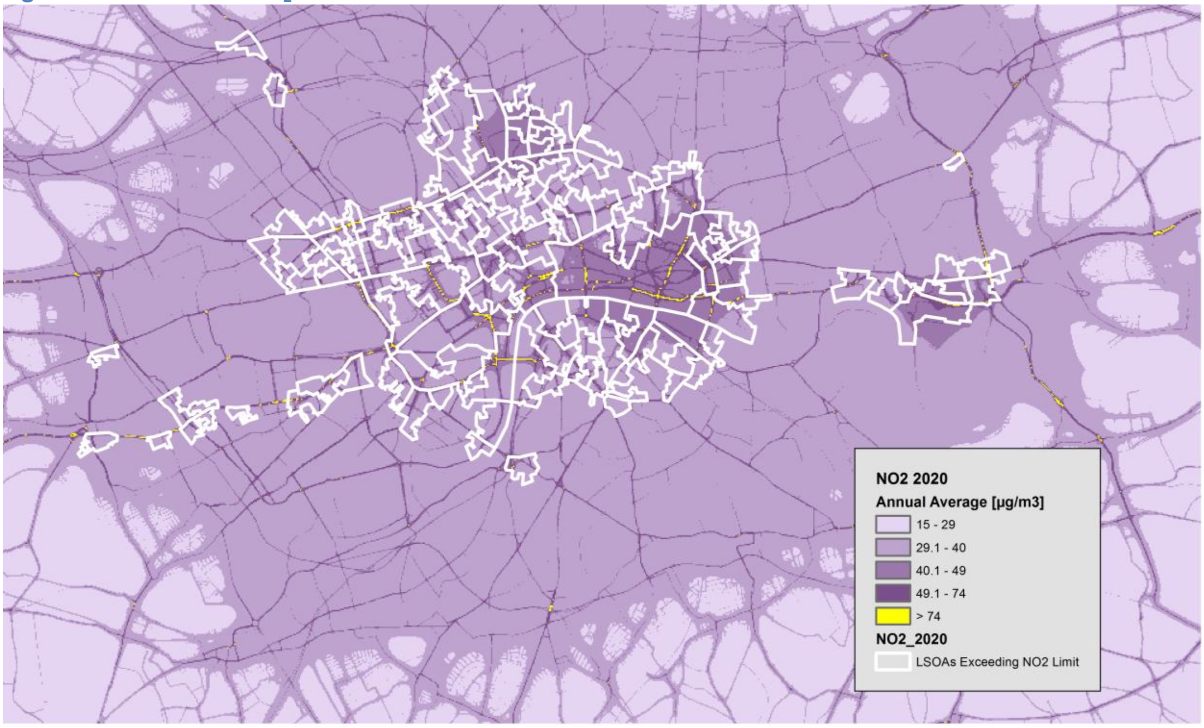


7.3 Locations of areas exceeding EU Limit value

Pollution concentrations will be significantly lower in most areas by 2020, reducing the number of people exposed to poor air quality compared with the present. However there are still exceedences of the EU limit value for NO_2 predicted in 2020 based on the modelling which includes planned measures. These are all located in Inner London as shown in **Figure 14**.

Targeted further measures are required to bring NO_2 concentrations in these locations down to within the EU limit value. The recently announced Mayor's package of air quality plans and measures are expected to improve the air quality in these areas but the likely impact on exposure of these measures has not yet been quantified.

Figure 14 LSOAs with NO_2 exceedence of the EU Limit value in 2020



8 Conclusions

This study has found that there is currently significant exposure of the London population to levels of NO_2 above the EU limit value and that this exposure is predicted to decline significantly (86%) by 2020. However, current modelling results show that in 2020 there will still be more than 300,000 people living in locations with average NO_2 above the EU limit value. In contrast, average concentrations of particles (PM_{10} and $PM_{2.5}$) were, by 2010, already within EU Limit Values for the annual average concentrations.

Populations living in the most deprived areas are on average currently more exposed to poor air quality than those in less deprived areas. 51% of the LSOAs within the most deprived 10% of London have concentrations above the NO_2 EU limit value. This is in contrast to 1% above the NO_2 EU limit value in the 10% least deprived areas. However there is a wide variation in pollution concentration values across the social gradient, with all deciles showing a large range between minimum and maximum values. Inequalities are predicted to reduce by 2020 as a result of new policies predominantly resulting from reductions in road transport emissions. Further measures and plans announced recently (and not included in the modelling) are expected to improve this picture.

Newham, Brent, Redbridge, Hackney and Tower Hamlets are the Boroughs that have the highest proportion of most deprived populations (top 30% deprived) in London's areas of worst air quality. Tower Hamlets, Camden, Southwark, Islington and City of Westminster are the Boroughs that have the highest numbers of people living in London's worst air quality areas. These Boroughs in particular need targeted action to reduce inequalities in access to clean air.

In 2010, there were 1777 primary schools in London of which 433 were in locations where average concentrations exceed the NO_2 EU limit value. Of these 433 primary schools, 82% were deprived schools. By contrast, of the 1344 primary schools that were not exposed to above EU limit values of NO_2, 39% were deprived. In combination with other measures to reduce pollution, we recommend that consideration should be given as to what further action can be taken at schools particularly those in deprived areas. The numbers of schools exposed to levels above the EU limit value is predicted to significantly reduce by 2020 but there is still a clear disparity between deprived and non-deprived schools.

The predicted air quality maps used in this analysis included planned measures to reduce air pollution emissions but did not include the impacts of further additional measures and plans recently announced by the Mayor of London. These are expected to further improve the air quality by 2020 beyond that quantified here. The Ultra Low Emission Zone is planned to focus specific reductions in the central London area and will help to reduce exposure to the highest levels predicted for 2020. It is also important that these further measures target improvements in deprived communities in an effort to reduce inequalities in access to clean air and therefore to help reduce health inequalities particularly among children.

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